ABSTRACT

LUMINESCENCE DATING OF CERAMICS FROM ARCHAEOLOGICAL SITES IN THE SODA LAKE REGION OF THE MOJAVE DESERT

By

Andrea C. Bardsley

August 2009

Ceramic studies in the Mojave Desert of California have long been plagued with vague and imprecise chronological data and have relied heavily on relative dating methods in discussing the antiquity of ceramics from this region. Luminescence dating offers an excellent means of generating a ceramic chronology directly from the ceramic samples found in the archaeological record. Soda Lake has a long and well established history of human occupation and is an excellent location to study the earliest forms of pottery in the Mojave Desert. This study successfully uses Optically Stimulated Luminescence dating techniques to date the manufacture event of each ceramic sherd and generate an approximate age for the occupation of sites along the Soda Lake playa.

LUMINESCENCE DATING OF CERAMICS FROM ARCHAEOLOGICAL SITES IN THE SODA LAKE REGION OF THE MOJAVE DESERT

A THESIS

Presented to the Department of Anthropology

California State University, Long Beach

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts in Anthropology

Committee Members:

Carl P. Lipo, Ph.D. (Chair)
Hector Neff, Ph.D.
Daniel O. Larson, Ph.D.

College Designee:

Mark Wiley, Ph.D.

By Andrea C. Bardsley

B.A., 2006, University of California, Santa Barbara

August 2009

WE, THE UNDERSIGNED MEMBERS OF THE COMMITTEE,

HAVE APPROVED THIS THESIS

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By

Andrea Bardsley

COMMITTEE MEMBERS

Carl P. Lipo, Ph.D. (Chair)	Anthropology
Hector Neff, Ph.D.	Anthropology
Daniel Larson, Ph.D.	Anthropology

ACCEPTED AND APPROVED ON BEHALF OF THE UNIVERSITY

Mark Wiley, Ph.D.
Associate Dean, College of Liberal Arts

California State University, Long Beach

ACKNOWLEDGEMENTS

One of the true pleasures in completing a task such as this is the opportunity to thank the many people involved. I would first like to thank all of my committee members, especially Dr. Lipo who initiated the fieldwork and supported my work consistently throughout the project. Dr. Neff offered his expertise frequently and freely, and was always available to aid in the study's technical aspects. I also owe much to Ms. Sachiko Sakai. Without her assistance the laboratory portion of this work would not have been possible, and her tolerance of my endless questions was much appreciated. Thanks should go to the Mojave National Preserve for permitting this study to take place within their borders. David Nichols was especially helpful in all aspects of the fieldwork, and I am most grateful for the enthusiasm, knowledge, and wisdom he shared. The Judith Presch Scholarship Fund at CSU Fullerton aided in funding this project, as did the CSU Long Beach Provost Research Stipend Program. I would also like to thank everyone who trudged out into the desert to help me collect samples, especially Maureen Lynch, Tony Quach, and Jessica Jaynes. Finally, thank you to my family for inspiring and indulging my love of archaeology and to Michael for your constant love and support through this ordeal. Without each contribution, the following study would not have been possible. Thank you all, again and again.

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CHAPTER 1

INTRODUCTION

All correctly constructed scientific inquiries within archaeology seek to explain aspects of the material part of the archaeological record. All the evidence in studies of archaeology must come from the physical remains of human activity. While researchers have at their disposal the complete archaeological record from which to draw questions, it should be remembered that it is impossible for archaeologists to catalog each gradual step of the continuous actions of humans in the past (Neff 1996: 245). Rather, what archaeologists have to work with is the physical evidence of human activity, like a ceramic potsherd in the midst of an expansive desert. It is the task of an archeologist to tie the present evidence to past events that created the form and dictated the presence of the evidence in its current state.

In order to set up a valid scientific inquiry of the archaeological record, a researcher must clearly delineate what is part of the phenomenological, physical world and the ideational terms used to describe and measure the world (Dunnell 1971). Scientific explanations of physical phenomena are generated by first creating ideational measurement tools and applying them to the real world. The explanation comes when the ideational tools work to describe or predict phenomena over the course of numerous

applications or tests. For studies in archaeological ceramics, it is especially important not to confuse the ideational tools of "types" or "complexes" with the basic phenomena that must be explained; in this study, the phenomena are human made ceramics found in the vast and windswept landscape of the Mojave Desert in California.

To successfully provide explanations for the current state of the archaeological record, one cannot attempt to create a narrative connecting the artifacts or formulate "just so" stories to tell about the human past. All too often, studies of archaeological ceramics use ideational tools which focus on measuring differences between artifacts to invent narratives around the artifacts. In creating ceramic typologies, archaeologists employed an excellent tool for gauging the dissimilarity between ceramic phenomena. Then, reifying their ceramic "types" by giving them names that tied the ceramics to existing cultures (see Rogers 1936), many ceramic researchers attempted to use the archaeological record to tell elaborate stories of dynamic cultural shifts and to spin tales about the tribes of people that originated the prehistoric ceramics. By confusing the ideational measurement tools with the phenomena itself, many ceramic studies veered from explanatory goals and into the realm of story-telling. Though sweeping stories of cultural emergence and decline or of human conflicts in the deep past are aesthetically enjoyable, they should not replace attempts to scientifically explain measurable changes in the archaeological record.

To expand the explanatory power of archaeological inquiries, ceramic studies must clearly separate the ideational tools of measurement from the phenomena that

require an explanation. Researchers frequently argue over the definitions of ceramic "types," forgetting that these types are ideational measurement tools, not actual phenomena. It is the ceramic sherds that require explanation, not the types. To further expand the explanatory power of ceramic studies, researchers must venture beyond tools which are useful only for describing the dissimilarity between artifacts. Ceramic "types" are excellent measurements of differences between ceramics, but fail to consider similarity and relatedness among ceramic artifacts. Researchers must adopt a way of viewing and measuring archaeological artifacts that can track their relatedness through time rather than just focusing on their differences. This requires an assessment of the archaeological record from a materialist point of view, where researchers use tools to measure the variation that constitutes the past and of which the present record is "just a terminal snapshot" (Lyman et al. 1997: 93).

Unfortunately, much of the previous research done in the Mojave Desert has attempted to create blanket narratives of past culture-types in the region rather than attempting to explain the measurable variation in the extant archaeological record. As some of the early experts in Mojave archaeology pointed out, "any study pursued by the archeologist regarding ancient man in this country is necessarily such a small portion of the great story as a whole that it can at the best reveal but fragmentary evidence" (Campbell and Campbell 1937: 37). Though the Campbells wisely point to the limitations inherent in any archaeological study, and indeed any scientific study, of the phenomena in the world, this statement exemplifies the fundamental misconceptions of

many archaeological researchers. The goal of every archaeological inquiry is to explain the archaeological record. The entire archaeological record is present for the researcher to examine and is at the archaeologist's disposal to test various explanations for the phenomena in that record. These explanations will never come in the neat narratives sought by novelists or historians or offer an account of the great story of ancient man. Rather, archaeological explanations will account for the presence of the artifacts in the archaeological record (Dunnell 1971) and, when set up in a materialist framework, will measure the relationships between artifacts through time (Neff 1996).

Researchers who spent time examining the archaeological record in the Mojave made the mistake of mixing their ideational measurement tools up with the phenomena they studied (see Rogers 1936). Because ceramics made up a relatively small part of the archaeological record in the Mojave Desert and were assumed to represent only late human occupation, ceramic studies were rarely the main focus of archaeological inquiries in the region. Further, due to the lack of decoration on these ceramics, they were typically categorized as utilitarian wares which could not be separated into the conventional culture-historical types. Ceramic samples from this area were frequently lumped together as "buff wares" (Colton 1958) or separated purely by geographic location (Colton 1945), and it was assumed that there was little or no temporal differentiation between them.

However, luminescence dating provides a method of dating individual ceramics and allows for ceramic chronologies to be created. Once a timeline is established, it is

possible to measure other attributes of the ceramics and to detect relatedness and variation trends between artifacts through time. This pilot study represents a first step toward a better chronology for the ceramics in the Mojave Desert and begins the process of expanding ceramic studies to document and explain the changes in ceramic phenomena through time.

The following investigation of prehistoric ceramics originating from the Soda Lake region of the Mojave Desert explains how optically stimulated luminescence techniques can be used to generate ages for individual ceramic sherds. Chapter 2 briefly describes previous archaeological studies within the Mojave Desert and discusses how ceramic studies have been traditionally conducted in American archaeology. In chapter 3, the principles of luminescence dating and optically stimulated luminescence techniques are outlined. Chapter 4 discusses the data requirements of the luminescence study and describes the field methods used to obtain ceramic samples from Soda Lake. An analysis of the results of this study is offered in chapter 5. Finally, chapter 6 provides some examples of future research made possible by the ceramic chronology generated with this study in the Soda Lake region of the Mojave Desert.

CHAPTER 2

MOJAVE DESERT BACKGROUND

The Mojave Desert encompasses a significant portion of southeastern California and extends into Arizona, Nevada, and southern Utah. It is characterized as a high desert and is surrounded by the Tehachapi, San Gabriel, and San Bernardino Mountain ranges. The desert boundaries are generally defined by the presence of the Joshua tree (*Yucca brevifolia*) which is considered the indicator species of the region by most biologists (Munro et al. 1992). As far as resources for both humans and other animal inhabitants, the Mojave is characterized by large areas of relatively unproductive habitat punctuated by resource patches of varying value to human and animal life (Sutton et al. 2007). This study focuses on an area in the central Mojave called the Soda Lake Playa, not far from the terminus of the Mojave River which runs underground along most of its course and ends near the western edge of the Mojave National Preserve (Wells et al. 2003). The area has been alternately referred to as the Mojave Sink or Mojave Lake regions, and has had a geologically and hydrologically dynamic past. The Mojave Desert is a unique environment in North America that has an equally interesting history both ecologically and with regards to its human occupation.

It is well accepted that human occupation in the Mojave Desert dates to at least the Late Pleistocene, a geologic period which ranges from approximately ca. 18000 to 8000 cal B.C. and corresponds to climate conditions that were generally cool and wet (Sutton et al. 2007). The Soda Lake region at this time would have been covered by a large perennial lake that encompassed the modern Silver Lake and Soda Lake playas. This area is termed Pleistocene Lake Mojave by paleohydrologists (Wells et al. 2003). Paleoindian archaeological deposits are found to date to cal 8000 cal B.C. and there is ample evidence that human inhabitants took advantage of Lake Mojave during this time period.

The area had such a distinct human presence during the Early Holocene, dating from cal 8000 to 6000 cal B.C. that the major "culture complex" of the region from this time period is called the Lake Mojave Complex (Campbell and Campbell 1937; Sutton et al. 2007). Relative to the rest of the Mojave Desert region, intense human occupation occurred at Lake Mojave until a drying period at the end of the Early Holocene brought on by cooling temperatures (Wells et al. 2003). Around 6700 cal B.C., Lake Mojave had dried up completely (Wells et al. 2003) and the definitive "culture complex" of the region came to a close.

Ranging from about 6000 to 3000 cal B.C., the Middle Holocene was characterized by a much warmer and drier climate even than modern times (Sutton et al. 2007). Though several culture complexes have been defined for the early parts of this time period, there is a markedly lower density of archaeological sites dating to the end of

this time period in the Mojave region (Sutton et al. 2007). It has been suggested that beginning around 3000 cal B.C. an occupational hiatus began, and the Mojave region was largely abandoned until about 2000 cal B.C. (Sutton et al. 2007: 241).

The Late Holocene, the geologic epoch that carries us to the present, began around 3000 cal B.C. This period is marked by a number of climatic changes that would have drastically altered the landscape of the Mojave, including the Soda Lake region. In fact, Soda Lake would periodically fill and dry out several times throughout this time period (Wells et al. 2003) though it would never near the highstand water levels of Pleistocene Lake Mojave. The most recent, persistent filling of the Soda Lake playa was during a climatic shift known as the Little Ice Age. This climatic phenomenon lasted from cal A.D. 1400 to about 1875, and the water levels at Soda Lake would have peaked around A.D. 1560 (Wells et al. 2003). The Late Prehistoric period, which began during the Late Holocene around cal A.D. 1100, saw the emergence of ceramic technologies and is of particular interest in this study.

Archaeology in the Soda Lake Region

Despite its modern desolation and inhospitable appearance, the Soda Lake region has attracted the attention of archaeologists since at least the 1920s. Many of the early studies of the region focused on lithic artifacts, since they are generally more abundant and are of greater antiquity than other archaeological artifacts (Warren 1984:348). Rogers (1929) published one of the early studies of the "Mohave Sink" near Soda Lake in which he investigated several prehistoric turquoise quarries. Rogers (1929:12) also made

observations that suggested trade between the Mojave and coastal California, which have largely been supported by modern studies. He attempted to show archaeological connections between the prehistoric Mojave and "Puebloan" regions in Arizona along the Colorado River (Rogers 1929:13). Campbell and Campbell (1937) were the first to place human occupation in the Mojave Sink in the Late Pleistocene and defined several of the lithic technology complexes that are still discussed in current archaeological literature.

Ceramic studies did factor into the archaeological investigations of the region, though to a lesser degree. Studies of the pottery of the Mojave sink had been historically difficult since "one finds sherds which are probably two thousand years old side by side with those of the eighteenth and nineteenth centuries" (Roberts 1929: 9). Roberts (1929) and some of his contemporaries who worked in the Mojave region through the 1950s (e.g., Colton 1958; Schroeder 1958) spent decades detailing and defining various pottery "types." They argued over the geographic boundaries of these types and to which indigenous cultures they could assign the artifacts (Colton 1945; Rogers 1936). Throughout even these earliest of discussions concerning Mojave ceramics, it was made clear that without some sort of "cultural stratigraphy" (Rogers 1929:9) all ceramic studies in the region would remain in the realm of conjecture and hypothetical explanation. What was actually lacking was not a defined cultural progression of the region, but rather a testable ceramic chronology.

While the Mojave region had an extensive human occupation, the use of ceramic technologies came relatively late in that occupation. Lithic materials are generally more

abundant in the archaeological deposits, both because their use began at a greater antiquity and because their preservation is generally better in the harsh environments of the Mojave Desert (Warren 1984). Most of the early studies of ceramics were surface collections (Rogers 1929; Campbell and Campbell 1937), and so even relative dates for ceramic types were not established through excavation but rather with associations to other artifacts.

The descriptions of the pottery sherds and early researchers' attempts to categorize them were detailed and valuable. For instance, Dobyns and Euler (1958) meticulously described the paddle-and-anvil construction, dark paste coloring, coarse opaque-quartz or granite temper of the "Tizon Brown Ware" ceramic type. Schroeder (1958) described a type called Lower Colorado Buff Ware that was characterized by a well-sorted clay free of inclusions with quartz and mica tempers and often of a reddish or black color. Since little was known about the chronology of these ceramics, categorizing the artifacts through the landscape became a focus of Mojave ceramic researchers. Consequently geography played a large part in these type definitions. While the Soda Lake region was not included in either Tizon or Lower Colorado Buff Ware definitions, the type descriptions fit several of the sherds discussed in this study. While valuable for clarity of definition, ceramic typologies are inherently subjective and reduce the amount of variability that can be measured by placing all focus on the differences between defined types (Lyman et al. 1997).

In the absence of a practical manner of testing the cultural historical chronologies, scholars of Mojave Desert ceramics attempted to create relative chronologies based solely on their typological definitions. Some ceramic studies began to link archaeological ceramics to contemporary native tribes and attempted to assign cultural affiliations to the artifacts. Though archaeologists like Rogers (1939:2) were initially careful to note that their named artifact "types" were made by researchers and should not be confused with distinct human cultures, Rogers himself later called one of his prehistoric ceramic types "Yuman" because of its perceived similarity to the modern pottery produced by Yuman tribes in Arizona (Rogers 1939). Other researchers, like Harold Colton (1945), used terms like "Patayan" types to distance the archaeological artifacts from modern cultures, but still made the mistake of assuming that human cultures could be, and indeed were, defined by the artifact types (Lyman et al. 1997). In creating their ceramic types, Colton and other researchers in the Mojave assumed that ceramic types equated to cultural relationships; that "related forms were related because they were similar . . . [when in fact] . . . similar forms are similar because they are related" (Lyman et al. 1997:98). Declaring culture relatedness and then finding similar potteries to fit the definition is scientifically placing the cart before the proverbial horse, an action which erases any chance of tracking variability and change through time in ceramic studies. However, once the notion of tying pottery to specific cultures or "culture complexes" (Sutton et al. 2007) had taken hold it was difficult to discard. Ceramic experts in other regions were making similar mistakes, and though they knew to

some extent that the ceramic types were a tool of measurement created by the researcher, archaeologists still began to speak of the types "as though they had some sort of independent existence" (Phillips et al. 1951:66). By the time Claude Warren (1984) wrote his definitive work on the California Deserts cultures and typologies had become interchangeable words, and with few exceptions (see Bettinger 1986; Lyneis 1988) most researchers were comfortable assigning cultural affiliations to ceramic artifacts through their typological definitions.

Ceramic Studies

Variability in ceramics can be studied to emphasize change over time, and there are many examples of studies demonstrating this (Feathers 2006; Eerkens et al. 2002). Though many experts in Mojave ceramics have tried, "archaeologists cannot expect simply to extrapolate the processes of innovation and transmission observed among living groups to account for the diversity in the archaeological record" (Neff 1996:244). Any ceramic study that is meaningful in explaining the archaeological record must be able to measure the variability in ceramic artifacts as they change through time.

One example of how the study of ceramics, unfettered by the use of empirical ceramic "types," can be applied successfully to an explanation of the archaeological record is James Feathers's (2006) examination of shell-tempered ceramics in eastern North America. Arguing against speculations of maize-based cultures replacing more local ones during the Late Woodland, Feathers (2006:101) points out that pottery changes do not necessarily mean wholesale culture changes and instead argues for an explanation

of the change in pottery during the Late Woodland. By measuring various attributes of sand-tempered pottery sherds against those of shell-tempered pottery, Feathers was able to show that shell-tempered pottery was stronger and more resistant to fracture (Feathers 2006:111). In many areas, he also showed that there was a selection toward these stronger, shell tempered ceramics and that they became generally more abundant over time (Feathers 2006). His explanation for this change was linked to environmental changes, pointing to lower firing temperatures caused by a change in available fuel sources (Feathers 2006). Lower firing temperatures required the addition of shell-temper to achieve a comparable strength to that of high fired sand-tempers in the final ceramic product. Feathers (2006:112) was careful to point out that selection trends are regionally specific and that certain areas showed earlier emergence of shell-temper, while in others shell-tempered ceramics never outnumbered sand-tempered ones. The subtle changes between ceramics of different regions and the factors guiding the selection of shell-tempered pottery would have been lost if a simple ceramic typology had been used as an explanation of how one culture replaced another in Eastern North America. For instance, terms originally created to describe artifact types like "Hopewell ceramics," become sagas of Mississippian culture encroaching on and eventually replacing Hopewellian cultures (Dragoo 1976). When used like this, ceramic typologies reduce the ability to track change over time when the types are attached to whole "culture complexes." But, by measuring artifact attributes independent of type archaeologists can begin to discern and track the changes in ceramic artifacts throughout history.

Ceramic studies of this nature can be used to explore a number of questions relevant to archaeological research. Traditional ceramic typologies are forced to restrict their inquiry to differences between the ceramics, but an evolutionary approach allows and requires artifact similarities to be measured as well (Neff 1996). Since "similar forms are similar because they are related" (Lyman et al. 1997:98), the relatedness between artifacts becomes a topic of inquiry in an evolutionary approach. Similarities between a limitless number of identifiable attributes can be measured when the ceramics are studied through an evolutionary perspective. Ceramic studies can then be used to investigate changes in mobility among hunter-gathers through history (Eerkens 2003), or exchange of technology and ideas between regions (Eerkens et al. 2002), or even trade and exchange of physical goods between peoples over time (Blomster et al. 2005). Researchers of archaeological ceramics who take an evolutionary approach have a way of explaining the relationships between artifacts and a means of measuring change through both temporal and spatial dimensions. Naming ceramic "types" has the unfortunate result of ignoring all similarities between the types and glossing over differences in attributes within the named "type." While typological studies are excellent at defining differences between the named types and allow for the development of satisfying nomenclatures, any useful ceramic study must also be capable of measuring both the differences and the similarities between artifacts throughout time and space.

In the case of the Mojave, ceramic studies have been mostly limited to definitions of types based on differences on outward appearance and geographic distributions.

Measuring relatedness though time is a key factor in every useful ceramic study and chronology plays a major role in any complete ceramic investigation. Though the long human occupation of the Mojave Desert is well accepted and ceramic types from the area have been a topic of academic discussion for nearly a century, little work has been done on the chronology of ceramics from the region. Before any explanations for the origins and influences of the pottery from the Mojave can be made, a chronology for these ceramics must be established.

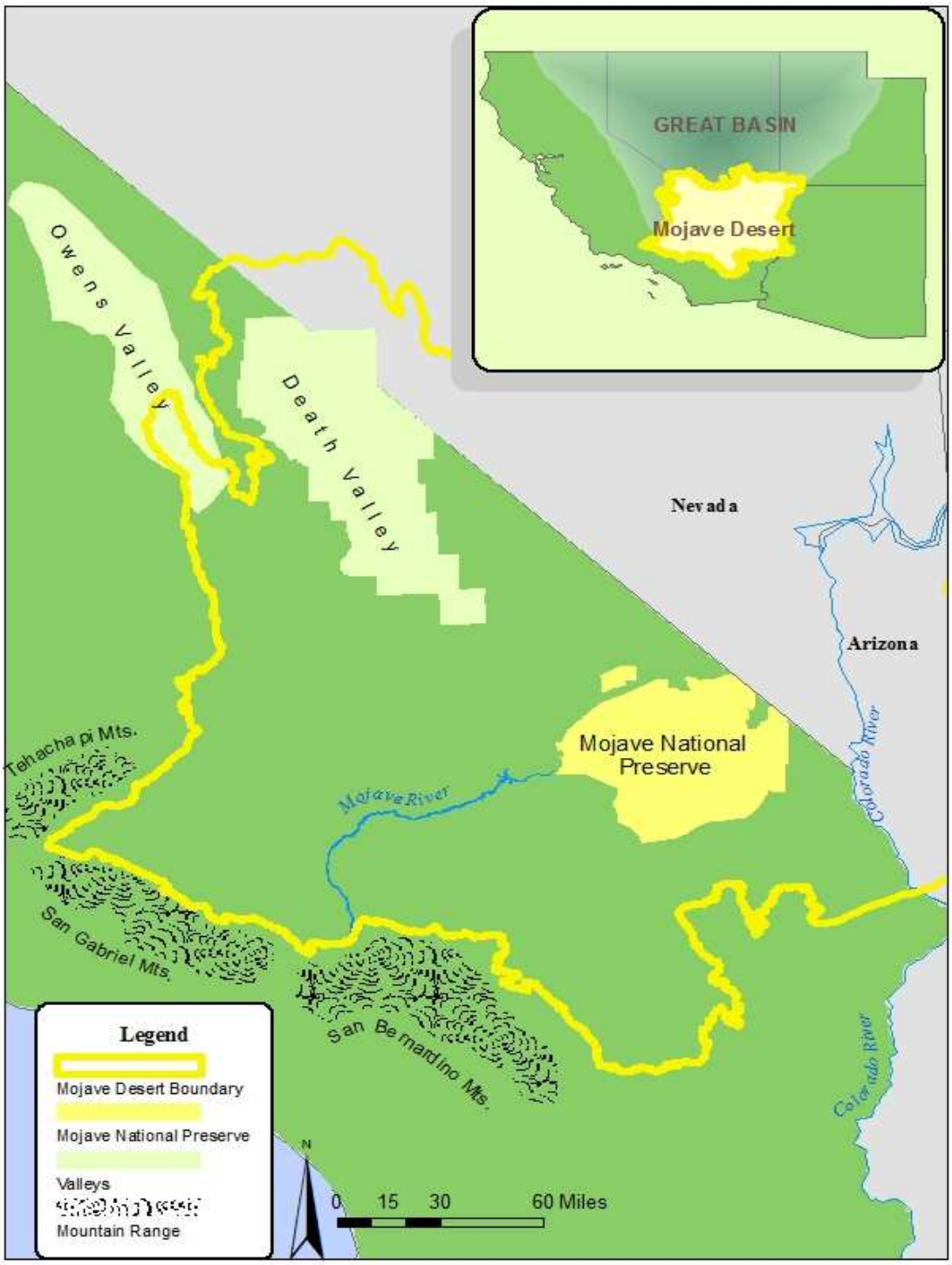


FIGURE 1. Area map of the Mojave Desert.

CHAPTER 3

METHODS

In an effort to create a preliminary chronology of ceramics in the Mojave region, data concerning the age of such ceramics must first be generated. As shown in the previous chapters, there have been attempts to establish relative chronologies of ceramics from this region. However, few if any, archaeometric studies have been conducted in this region. Absolute dates are rarely discussed in the archaeological literature concerning the Mojave. Though this particular project is limited geographically to the area surrounding Soda Lake in California, future studies could easily encompass larger areas of the Mojave Desert. This pilot study verifies that precise dates can be obtained from archaeological sites in the Mojave by the use of luminescence dating techniques.

The ability to generate dates or ages from luminescence signals is what makes luminescence dating a useful technique for archaeologists. Since the techniques date past exposure to heat and light, luminescence dating is particularly well suited to archaeologists who are interested in questions about the formation of pottery in the past. With many other dating methods it is essential to distinguish between the actual dating event and the archaeologically significant target event for which an age is desired (Dean 1978). In the case of dendrochronology, a dating method based on the annual creation of tree rings and used widely in the North American Southwest, the target event is usually

the construction of a building or the occupation of a site, while the actual dated event is the felling of a particular tree (Walker 2005:130). This can produce a problem when situations of found wood or reused wood are considered in their archaeological contexts (Dean 1978). Similarly, radiocarbon analysis dates the removal of the sample of the global carbon reservoir, or more simply stated, it dates the death of the organic matter being sampled (Walker 2005). In most archaeological investigations, the date of interest is the site occupation or some other human interaction with the environment, and not necessarily the death of the plant or animal matter in question. Therefore, many of the traditional dating methods require bridging arguments to link the dating events to questions of archaeological interest (Feathers 2003:1495). Since luminescence dates can be derived directly from human-made pottery sherds and refer to the time at which the pottery was fired, there are no bridging arguments required. The target date and event date are one and the same when using luminescence dating techniques (Feathers 2003). The target date of interest in this study of Soda Lake ceramics is the manufacture of the pottery, which can be gained through luminescence dating techniques. But, a brief explanation of the general methods used in this study is required before the particular techniques followed can be addressed.

Principles of Luminescence Dating

The natural phenomena of luminescence has been observed and studied for several centuries. As early as the seventeenth century, luminescence was described as a property of certain materials, evidenced by Robert Boyle's 1663 observations of "A

Diamond that Shines in the Dark" which were presented to the Royal Society of London at that time (Aitken 1985:3). In the paper, Sir Boyle observed that a diamond, which is a specific form of crystallized carbon, could give off a small amount of light when it was exposed to an energy source for a period of time (Aitken 1985, 1998). A number of other crystalline minerals possess luminous characteristics as well; that is they absorb energy from some external source and are able to emit it later in the form of light (Feathers 2003:1493). Far more common than diamonds, minerals such as feldspar and quartz also luminesce under certain conditions and are minerals which occur frequently in the pastes and tempers of archaeological ceramics (Feathers 2003). Generalizing from observations made by physicists of the quantum configuration within crystals, it is assumed that the structures of these crystalline minerals contain small low-energy defects in their lattice work that can collect negatively charged electrons. These defects are referred to as "traps" (Aitken 1985:42). The electrons remain trapped within this crystal structure until they are forced out by an external stimulus. Once the traps are emptied, they begin accumulating new electrons at a constant rate. This allows the time of the last emptying, or "zeroing event" to be determined (Feathers 2003:1494). Zeroing events that naturally reset the luminescence clock include extreme heating, such as in the case of fired pottery, or exposure to sunlight, in the case of buried sediments or quartz ceramic tempers (Walker 2005).

While perceptible to the human eye in some cases, luminescence was not measurable in any practical sense until the invention of the photomultiplier tube (PMT) in

the mid-1930s (Aitken 1985). Photomultipliers are capable of measuring individual photons by turning them into electrical pulses which are then converted into raw numbers related to the intensity of luminescence (Aitken 1985:7). Once the intensity of the light is measured, the traps are artificially zeroed and the sample is exposed to a laboratory source of radiation. The exposure is prolonged until the amount of radiation required to create the original luminescence can be calculated, and the amount of radiation is measured in "grays" (Feathers 2003). The gray units (Gy) represent the luminescence dose absorbed in a particular sample (Feathers 2003:1494) where "dose" is defined as the energy absorbed per kilogram in any luminescent mineral (1 Gy = 1 J kg^{-1}) (Aitkens 1998:39). By measuring the "natural dose" of luminescence in a sample, and comparing it to the proportion of absorbed signal artificially added in a laboratory setting, the age or date of the last zeroing event can be determined for a particular sample (Walker 2005:95). Michael J. Aitken (1985:9) offers this general age equation:

$$Age = \frac{Paleodose}{AnnualDose}$$

where paleodose is the total or accumulated dose absorbed naturally in the sample and the annual dose is the calculated rate at which the absorption occurs over time. Electron traps from the sample can be artificially emptied in a laboratory setting, and this is the basis of all luminescence dating. The controlled conditions under which the sample is forced to luminesce determines the dating technique; emission of light due to exposure to heat is called thermoluminescence (TL), while the forced release of electrons and

subsequent light emission created by exposure to specific wavelengths of light is called optically stimulated luminescence (OSL) (Walker 2005:94).

Optically Stimulated Luminescence (OSL)

While thermoluminescence was the first technique to be discovered and widely used by archaeologists, optically stimulated luminescence (OSL) dating is rapidly becoming the dominant technique in the field (Walker 2005:96). OSL dating is more useful in archaeological settings than TL dating because of its greater sensitivity. In minerals like quartz and feldspar, all electron traps are emptied by exposure to sufficiently high temperatures, but only some traps are emptied by exposure to light (Walker 2005:94). For archaeologists interested in ceramics, it is assumed that all traps are re-zeroed at the time of the pot firing, and with a careful laboratory process in place, portions of a pot sherd that have not been exposed to light since its firing can be directly dated using OSL. OSL dating can help to reduce error that results from spurious luminescence in TL analysis (Aitken 1985:45) and fading effects, which result from electrons escaping traps even at very low temperatures (Feathers 2003:1498). Given OSL's advantages, and the harsh erosion that affects other datable material in many Mojave Desert archaeological sites, this specific technique was chosen for creating a chronology for the Soda Lake ceramic assemblage in this study. However, some further detail on the OSL technique is required before the archaeology of this study is addressed.

As previously mentioned, the major difference between TL and OSL dating is the type of energy used to empty the electron traps in a sample during laboratory testing. In

the case of OSL, a beam of light is used to release the electrons (Walker 2005:96). For the majority of quartz sampled OSL studies, which include this Mojave study, high powered blue or green LED (light-emitting diodes) normally between 424 to 527 nanometers in wavelength are used to stimulate the samples and force them to luminesce (Aitken 1998; Walker 2005). The experiments in this study use a blue LED at a wavelength of 450 nanometers. Also, the dated event in OSL is the last exposure to sunlight for the mineral sample (Feathers 2003:1495). This event is quite useful to archaeologists studying ceramics, especially when care is taken to remove outer layers of the ceramic sherds, since the luminescence signal is zeroed at firing and the inner sherd particles are not re-zeroed by sunlight exposure, termed "bleaching" in OSL studies (Walker 2005:96).

The same basic ratio for generating ages is used in OSL as in other luminescence techniques. However, some different considerations must be made when calculating ages using OSL. James Feathers (2003:1494) offers a more detailed age equation for luminescence:

$$Age(ka) = \frac{D_E(Gy)}{D_R(Gy/ka)}$$

where D_E is the equivalent dose in grays and D_R is the average dose rate over time, and the ratio between the two is the age in some unit of time. In the equation, the equivalent dose (D_E) is defined as "the amount of radiation, in terms of absorbed dose, required to produce a luminescence signal equivalent to the natural one measured on the sample" (Feathers 2003:1494). It is measured by calibrating the natural signal with the laboratory

added radiation. The other variable in the equation, the environmental dose rate (D_R), is a measure of the radiation dose absorbed per unit of time since the zeroing event (Walker 2005:98). There are two components involved in the dose rate; an internal dose which is calculated from the radioactive materials within the sample and an external dose taken from radioactive materials in the artifact's external surroundings (Walker 2005:98). The internal dose rate is affected by short-ranged alpha and beta radiation absorbed from naturally-occurring radioactive elements, while the external dose rate is affected mainly by long ranged gamma and cosmic radiation (Feathers 2003:1494). Feathers points out that "the current dose rate is often assumed to represent the average dose rate because of the long half-lives, of the order of 10^9 years, of the major sources, ^{40}K, ^{238}U and ^{232}Th" (Feathers 2003:1494). This means that, before an OSL date can be obtained, the amount of potassium (K), uranium (U) and thorium (Th) must be measured and factored into the age equation.

Several different methods can be used to evaluate the paleodose of a particular sample, though each of them utilize the basic principles of luminescence. At their core, the differences between the methods are in experimental conditions and in interpreting the equivalent luminescence dose or D_E (see Aitken 1994, Aitken 1998; Murray and Wintle 1999 for more information). The present study is an example of the single-aliquot regenerative-dose method performed on mixed mineral particles, mostly comprising of quartz, extracted from the ceramic samples (Benjeree et al. 2001; Feathers 2003). In the regenerative dose method, the paleodose is calculated by a direct comparison between the

natural OSL measured at the start of the experiment with the OSL resulting from laboratory irradiation over an extended period of time (Aitken 1998:12). The term "single aliquot" refers to the number of sub-samples (aliquots) used in a single experiment. Unlike other methods where various sub-samples are tested under separate conditions, in this method repeated measurements are conducted on the same aliquot throughout the experiment (Duller 1995).

The basic procedure in this method begins with a low level preheating of the aliquot (Duller 1995:220). The low heat removes any unstable luminescence signals and guards against fading effects, as previously discussed. The "natural" luminescence signal of the aliquot is then measured by a stimulation of some known wavelength of light. This initial measurement is calculated from a graph called a "shine-down" graph, like the one in made for sample LB395 in Figure 2. Luminescence measurements are taken continuously during the first part of each experiment, resulting in a high spike of natural luminescence and a subsequently slow decline in the light emitted from the aliquot (Murray and Wintle 2000). The average of the initial spike, as indicated by the red lines in the graph, is calculated. A portion at the end of the curve is then averaged, designated by the green lines on the graph, and is assumed to be the background for that particular aliquot. The background intensity is subtracted from the intensity of the initial spike, and assumed to be the "natural" luminescence signal for the sub-sample. Next, the aliquot is effectively bleached by prolonged exposure to light or zeroed of signal by a high intensity heat. The sample is then artificially irradiated and the luminescence is again measured.

This process is repeated and charted several times in order to define the growth of the luminescence signal with the radiation (Duller 1995). The resulting graph is called a "growth curve" as the example in Figure 3 shows for sample LB395. The original, "natural" luminescence signal is marked on the y-axis, and the equivalent radiation dose that is required to make the same sized luminescence signal is marked by a red line on the x-axis. The result of the experiment is the "equivalent dose" or D_E converted into grays (Gy). The experiment is repeated over several aliquots from each sample, each resulting in a unique growth curve and equivalent dose which can later be averaged.

For the experiments to be valid, some assumptions concerning the conditions of the tests and the materials being tested must be made. First, the luminescence signal must be reduced to a minimal level between each irradiation and measurement attempt. It is also assumed that the processes of measurement, preheating, bleaching and irradiation do not alter the luminescence sensitivity of the aliquot or damage the luminous characteristics of the minerals being tested (Duller 1995:220). If either of these assumptions is incorrect, the accuracy of the result must be called into question. However, automation of the experimental process ensures that sufficiently low levels of luminescence are achieved between measurements (RISØ National Laboratory for Sustainable Energy 2009) and extensive studies have shown that quartz is resilient to sensitivity changes between radiation exposures in the laboratory (Murray and Wintle 1998; Murray et al. 2002).

Further, this single-aliquot regeneration (SAR) method has some distinct advantages over other approaches to finding equivalent dose in OSL tests. For one, there is no need for extrapolation of possible luminescence signals in this method (Aitken 1998:12). Rather, multiple tests are performed on a single sub-sample and a series of luminescence signals are recorded, allowing an accurate intensity to be mathematically interpolated from the data. This nearly eliminates uncertainty that stems from non-linear measurements of multiple luminescence signals (Aitken 1998). Also, as Murray and Wintle (2000:70) point out in their revised SAR explanation, since "the test dose signal has been used to correct the regenerated OSL response, the dose-response curves….show no sign of complex growth at low dose." This means that there are very few problems supralinearity of growth curves which sometimes plague other OSL studies (Murray 1998; Murray and Wintle 2000). Overall, the single-aliquot regenerative-dose method of OSL dating is one of the most accurate procedures in all luminescence testing, and so results in reliable and useful ages when applied to archaeological assemblages like the one in this study.

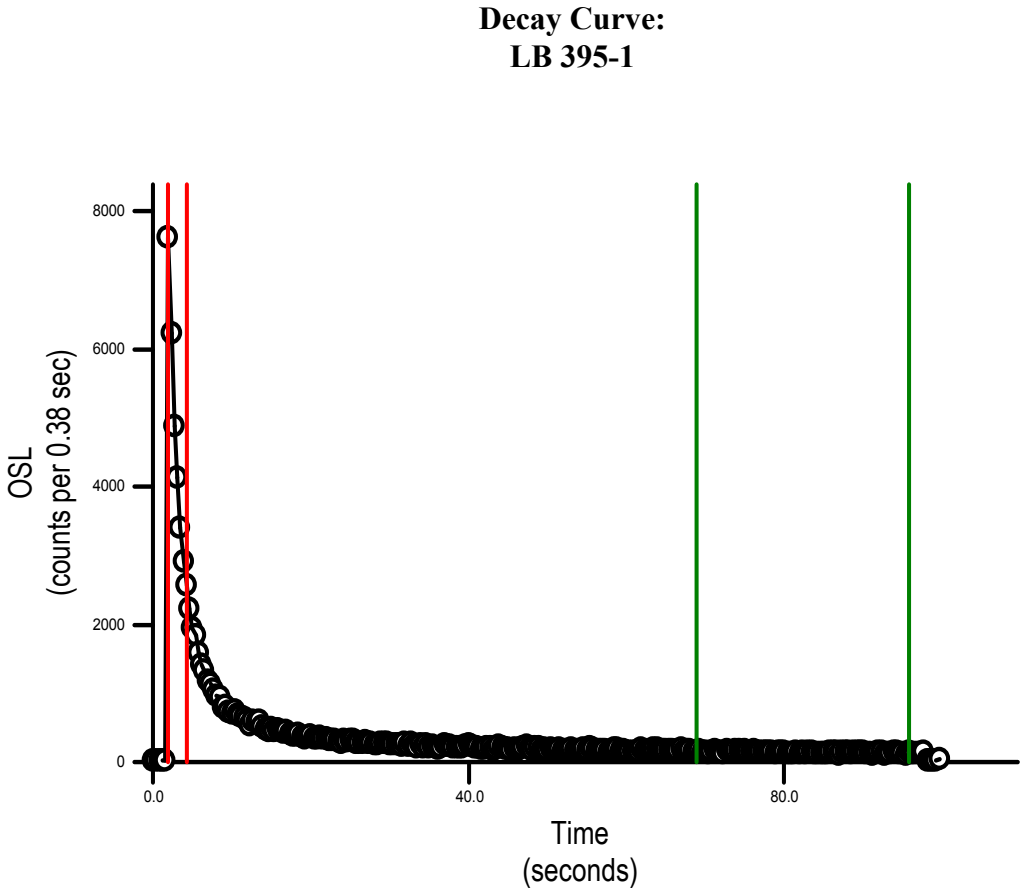


FIGURE 2. Example decay curve. A decay curve or "shine down" curve from a single aliquot from sample LB 395 showing the luminescence signal (highlighted in red) and the background luminescence (highlighted in green) used to calculate the age of the ceramic.

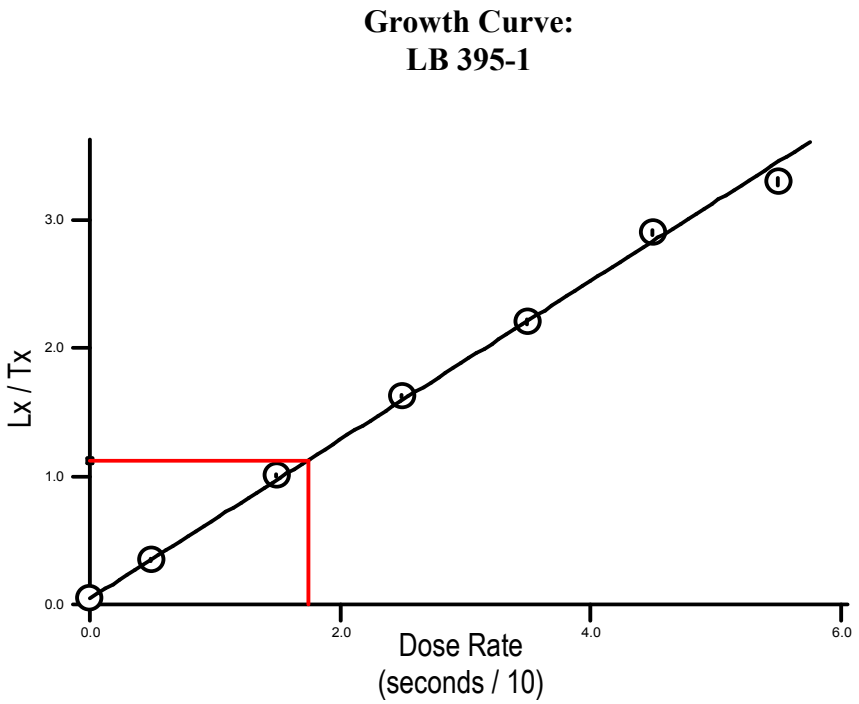


FIGURE 3. Example growth curve. Example of a regeneration growth curve used to calculate the dose rate for a single aliquot from sample LB 395. The natural luminescence is marked on the y-axis and the equivalent radiation dose required to make the same sized luminescence signal is marked by a red line on the x-axis.

CHAPTER 4

DATA REQUIREMENTS

With many of the general principles behind this study now illuminated, it is important to identify the kinds of data required and also to explain the specific methods used to collect, test, and analyze the Mojave artifacts which are the focus of this study. To reiterate, the goal of this study is to show that it is feasible in the Mojave Desert to generate accurate and scientifically sound absolute dates from ceramics through the use of optically stimulated luminescence dating. More traditional methods of creating ceramic typologies (Lyman et al. 1997) are difficult to apply to ceramics from the Mojave Desert region because many of these ceramics lack the discrete attributes like decoration on which such types often depend. In past ceramic studies, types were defined first and the temporal significance of the descriptions was tested later. For the Mojave, it may be more useful to construct a chronology of ceramics first in order to later explore and discover attributes which are temporally sensitive.

Laboratory Methods

All luminescence measurements in this study were made using a Risø TL/OSL-DA-15 combined TL/OSL reader that incorporates calibrated beta (^{90}Sr) radioactive sources for evaluating the rate of luminescence signal accumulation (IIRMES Laboratory

California State University Long Beach 2009). Each tested aliquot comprised of a mixed mineral sample with grain size between 1 and 8 μm. Due to the very fine grain size tested, samples were not subjected to hydrofluoric acid etching. Blue light OSL (BOSL) was used to stimulate each sample, with blue LED set to the 400-550 nm (nano-meter) range (centered at 470 ± 30 nm). Because there may be both quartz and feldspar crystals present in the sub-sample, and because the two minerals react differently to light stimulation, it is necessary control for luminescence that does not result purely from the quartz (Banerjee et al. 2001:76). In order to reduce the contribution of feldspar contamination, a double infra-red light exposure in the 800-900 nm transmission range was used between experiments (Banerjee et al. 2001). Feldspar and quartz react differently to infrared (IR) light (Banerjee et al. 2001), so by twice exposing and measuring IR stimulated luminescence, this difference can be factored into the error terms in the final date equation. Also, a Hoya U-340 filter supplied with the Risø reader is used eliminate spillover from stimulation blue light.

While the majority of the tests were consistent, a few samples were subjected to a slightly different set of experimental conditions. For most of the samples, only a beta radiation source was used to dose the samples. This is true for sample number LB-378 through LB-395 and LB-397 through LB-409, all of which were tested between April and May 2009. Aliquots made from LB-241 and LB-250 through LB-257, which represent ceramic samples collected from SBR-5417 in 2008, were subjected to both beta and alpha sources of radiation during dosing. However, only luminescence signal recorded from

the beta dosing was used in the following analysis. The sensitivity of each experiment was set to record all luminescence signal between 5 to 55 Gy from each sample. In creating the sub-samples, a portion of each ceramic was crushed and placed in a series of acid washes in order to isolate only luminescent crystalline minerals. An attempt was made to create and test five aliquots per ceramic sherd, however small sample size precluded this in some cases. A detailed protocol of all laboratory procedures followed can be found in Appendix B.

Field Methods

Luminescence dating is a destructive process, and at the very least a portion of every ceramic tested must be pulverized in order to extract the desired crystalline minerals. Since archaeological artifacts are a non-renewable scientific resource, care must be taken when choosing appropriate deposits from which to obtain samples. In this case, permissions also needed to be taken into account while collecting data. As a pilot study, a small area of the Mojave that had a rather dense number of sites with some quantity of ceramics was required. The area surrounding Soda Lake within the boundaries of the Mojave National Preserve met with all these requirements.

Within this area, ceramics were collected from five officially recorded archaeological sites. Additionally, three semi-dispersed isolate sherds which were not connected to official site were collected and tested. As many sherds with a diameter of 4 or more centimeters as were visible were collected from the surface of these sites. The size parameter was meant to reduce bias while collecting the samples and a total of 89

individual sherds were gathered. Of these, 40 sherds were selected to be tested for luminescence dating with care taken that each site was represented in the study.

Site CA-SBR-5417

Beginning on the west side of Soda Lake, site CA-SBR-5417 has an official report dating to 1979 (California Department of Park and Recreation [DPR], Archaeological Site Survey Record SBR-5417). Ceramics from this site were collected in November of 2007. The deposit is officially described as a "large camp site on the west side of sand dunes with artifacts and hearths visible in blow outs within the dunes" (DPR, CA-SBR-5417). At the time of collection, the area was approximately a 1000 square-meter area surrounded by large dunes that ran roughly north-south along the east and west sides with a single large dune at the northern end that ran east-west. Some minimal fragments of groundstone and flaked lithic debitage were visible, as were some charcoal deposits that did indicate hearths. A total of 9 ceramic sherds were collected and all were dated for luminescence dating from this site.

Site CA-SBR-3571

Approximately 1.2 miles to the south east lies site CA-SBR-3571. With an official record of survey dating from 1978 (DPR, CA-SBR-3517), the site remains in good condition with a relatively large scatter of pottery sherds protected by low dunes to the east, south, and west of the site. Despite some deflation of the surrounding dunes, some remnant charcoal of possible archaeological origin was present. The site is small, no more than 20 meters square, but had a large number of pottery sherds made from a

distinctive paste when compared to the other sites within this study. Even the original site record reports that the "pottery was a grey variant of local manufacture" (DPR, CA-SBR-3517). At the time of ceramic collection for this study, the site was still in very good condition and several of the ceramics collected may have been associated with a single pot-drop. A total of 34 sherds were collected from this site during two field surveys in September 2008 and February 2009, and luminescence testing was performed on 13 of these sherds.

Site CA-SBR-3570

A little over 500 meters due south, site CA-SBR-3570 is much smaller with a much more modest ceramic assemblage. Only about 8 to 10 square meters, this site is separated from SBR-3571 by a large, low sand dune and may be associated with this neighboring site. Both sites are located in gravelly ablation zones possibly associated with the Mojave River periodically flowing into the Soda Lake playa near this area (DPR, CA-SBR-3570). While this site was also in relatively good condition when examined in September 2008, it should be noted that the site has no evidence of human occupation outside of the ceramics present. Also, the ceramics are described as a "variation of Lower Colorado Buffware…and may be intrusive to the area" (DPR, CA-SBR-3570). Analysis of the ceramics from this site shows that the deposit contains a higher instance of slipped and burnished exteriors that the other samples from the other site, though this observation does not factor directly into this study. A full collection of sherds over the 4

centimeter limit, resulting in 7 ceramic sherds collected from site CA-SBR-3570. All 7 samples were dated using luminescence techniques.

Site CA-SBR-5421

Approximately ½ mile due east of these sites, nearing the proper edge of the Soda Lake Playa, lies site CS-SBR-5421. Also over 1000 square meter, this site is located in a large blow-out between shifting sand dunes. Several groundstone fragments, including a metate fragment, as well as some flaked lithic debitage were present at the site when it was surveyed for this project in February 2009. The presence of milling ground-stone fragments similar to other late historic period site suggested a rather late date for this site when the survey for this study was conducted (David Nichols, personal communication). A variety of ceramics, with visually distinguishable paste and color differences even in the field, were present at this site. So many, in fact, that they could not all be properly bagged and several samples fitting the over 4 centimeter criteria were not collected from the site. Several samples were collected well outside the 50x50 meter area officially designated as the site, and artifacts to the north might be associated with another nearby site. In fact, the original 1979 site record report that site SBR-5421 "may represent part of a larger occupation area" (DPR, CA-SBR-5421). However for the purposes of this study, all ceramics in this vicinity are assumed to be associated with site SBR-5421. In all, 32 ceramic sherds were collected from this site and 6 sherds were used in the luminescence portion of this study.

Site CA-SBR-1997

Finally, moving to the east side of the Soda Lake Playa, site CA-SBR-1997 is a very large site along the shore of the dry lake which was surveyed in September of 2008 for this study. Running along a roughly north-south axis at the foot of nearby Cowhole Mountain, this sprawling 160,000 square meter site was dominated flaked lithic debitage of various types of stone. Some hearth features with some associated mammal bone were present at the time of the survey, as was a small fully-articulated projectile point. The official site record also makes mention of groundstone fragments, utilized flakes, core tools, tortoise shell fragments, and ungulate tooth enamel fragments, among other artifacts and features (DPR, CA-SBR-1997). This site had few ceramics left at the time of this survey, though they ceramics are mentioned prominently in the original site record. Only 3 ceramic samples were collected from this vast site and 2 were dated using luminescence techniques.

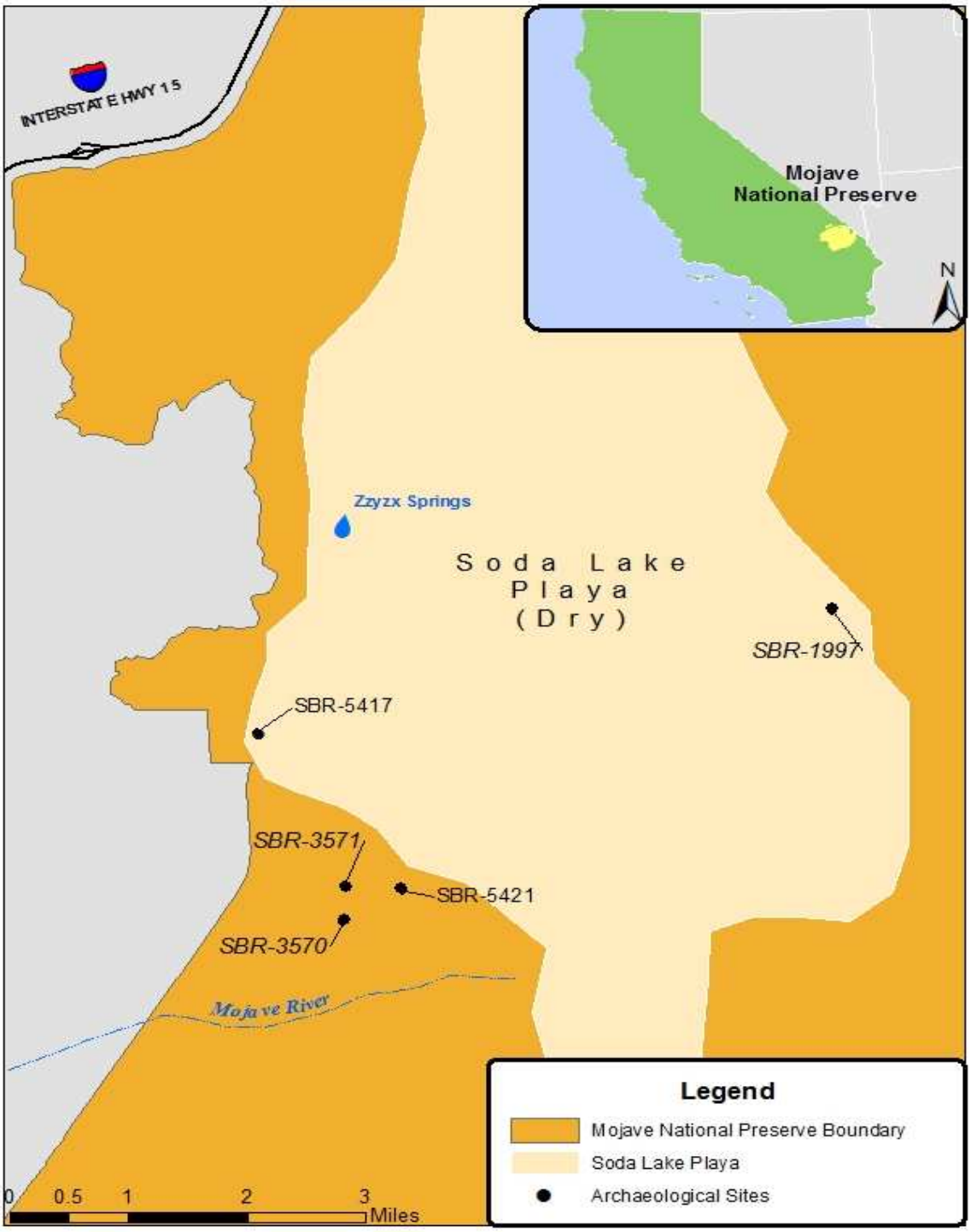


FIGURE 4. Soda Lake region and study areas.

CHAPTER 5

ANALYSIS AND RESULTS

One of the great benefits of luminescence dating, as previously mentioned, is the ability to directly date ceramic artifacts of archaeological significance (Feathers 2003). Taking all the assumptions inherent to the luminescence technique into consideration, the following ages described in this study relate to the event of manufacture of each specific ceramic sherd. It is assumed that the date of manufacture is in some way correlated to the date of occupation for a particular archaeological site or that the manufacture event is correlated to the sherd discard event in some way. Also supposed is that each ceramic pot has a single manufacture event, that a whole pot would be carried and moved by some human individual until the ceramic was rendered useless, and that the remains of a non-functional pot would then be discarded. While we only are able to date the manufacture event using OSL, it is assumed that a ceramic sherd's appearance in the archaeological record can be tied to this date. At the very least, the luminescence dates give an approximation of when humans discarded the ceramics at a particular site, since that event would necessarily come on or after the date of manufacture posed in this study. Also, since several samples were collected for most of the sites, a range of dates specific to the ceramics dated by luminescence techniques can be generated for each site. Hunter-

gatherers in this area frequently left and returned to areas in seasonal rounds, and may have periodically abandoned and re-occupied sites on a regular basis (Eerkens 2003). The information gained from this study is essential for understanding the activities of the prehistoric hunter-gatherers who occupied the Soda Lake region over an extended period of history.

It should be noted that all the dates in the following section are given in A.D. and derived from the OSL tests performed by the author, unless otherwise stated. Error terms are given in years, and each year is equal to one standard deviation. Sites in the area probably predate the use of ceramic technology, and so may in fact have been occupied long before the ceramic luminescence dates indicate. No calibrated radiocarbon dates appear in published literature for the sites examined and so do not factor into this study, though some charcoal and animal bone remains in this area and it would be quite interesting to compare dates to these samples. As previously discussed, luminescence dating requires a measurement of both internal and external sources of radiation, given in the form of annual dose or average dose rate (Aitkens 1985; Feathers 2003).

Dosimetry and Radiation Calibrations

In order to properly analyze the luminescence signal from a sample and to convert the signal into an intelligible age, the radiation sources both within the sample itself and from external radiation sources must be measured (Aitken 1998). The relevant and most common radioelements that must be tested in OSL dating are potassium (K), thorium (Th), and uranium (U) (Aitkens 1998:39). Additionally cosmic radiation, usually gamma

radiation that bombards the earth from sources in deep space and whose effects are altered at different altitudes (Walker 2005:8), must be factored into the calculation of the final OSL dates. For fine-grain samples where the mineral grain size is 10µm or less, such as the samples in this study, Aitken (1998:41) offers the following modified age equation:

$$Age = \frac{Paleodose}{kD_{\alpha} + D_{\beta} + D_{\gamma} + D_{c}}.$$

This equation incorporates beta radiation (D_{β}), gamma radiation (D_{γ}) and the effective alpha radiation (kD_{α}) absorbed from naturally occurring radioelements as well as the cosmic radiation (D_c) that affects the individual OSL samples. Combining these factors is, for practical purposes, equivalent to the average dose-rate (Aitkens 1998) as discussed in Chapter 3. Ultimately, it is this equation which was used to generate the ages for the ceramics in this study. Samples taken from surrounding soils and from each ceramic sherd are subjected to chemical analysis in order to accurately assess the contribution of the natural dose-rate to the age equation. The chemical analyses took two forms: laser ablated inductively coupled plasma-mass spectrometry (LA-ICP-MS) and X-ray Fluorescence (XRF).

Laser Ablated Inductively Coupled Plasma-Mass Spectrometry

Inductively coupled plasma-mass spectrometry (ICP-MS) is a type of chemical analysis with a multi-element detection capability of smaller than parts per billion (10^{-9}) on a wide range of materials (Pollard 2007:195). The technique measures elements

between ^{6}Li and ^{238}U based on their uniquely identifiable atomic masses, but is biased against lighter elements such as hydrogen (H) through argon (Ar). In the laser ablated type of ICP-MS, a laser is directed toward the sample, which in this study consists of two homogenized pellets made first from crushed ceramic sample and then from soil samples from the area surrounding each in-situ ceramic. The laser ablates a small part of the sample which is subsequently transported by a carrier gas mixture of helium and argon from the laser cell and introduced into the ICP-MS torch. Here, an argon (Ar) gas plasma capable of sustaining electron temperatures between 8,000 and 10,000 K is used to ionize the injected sample (Speakman and Neff 2002:138). The ions, which have unique masses for each of the different elements being tested, are counted in a Time of Flight (TOF) instrument in which all the ions of a certain weight hit a sensor at the same time and can be identified accordingly.

LA-TOF-ICP-MS can therefore offer accurate measurements of the relevant elements for calibrating optically stimulated luminescence dates, namely uranium (U), thorium (Th), and potassium (K). While this is a highly sensitive method, one difficulty occurs in ICP-MS that is a particularly problematic in OSL calibration. Since argon (with atomic mass 39.948) and potassium (atomic mass 39.0983) have similar masses, they are hard to distinguish using ICP-MS (Neff, personal communication). This is especially problematic when the argon (Ar) carrier gas is used, since the argon isotope ^{40}Ar is so near to the atomic mass of ^{39}K isotope leading to ^{39}K isotopes being measured as part of the argon gas background and eliminated from dosimetry calculations. For this

reason, a technique called X-ray fluorescence (XRF) was used to calibrate dates when possible. However, for samples from site SBR-5417, only ICP-MS analysis was available and a table of the U, Th, and K concentrations in parts per million can be found in Tables 4 and 5. A complete protocol of how LA-ICP-MS analyses were conducted for this project can be found in Appendix E.

X-Ray Fluorescence

X-ray fluorescence (XRF) is a surface technique also capable of producing multi-elemental analyses of concentrations within a sample. In this process, a sample is exposed to an X-ray which interacts with the component elements of the sample. During the process, a variety of energy transitions occur at the atomic level and secondary X-rays are emitted from the elements in the sample (Pollard 2007:101). These secondary X-rays hit a detector which can interpret the different energies as discrete elements based on their unique x-ray energies (Henderson 2000:15). An analyzer displays the spectrum energies as a series of peaks above the background, and the peaks are indicative of incidents of particular x-ray energies being detected over the course of the sample analysis. This can be converted into an elemental concentration based on the length of time the sample is exposed to the initial X-rays (Henderson 2000:16).

XRF is also a very sensitive technique and is capable of detecting elemental concentrations in the range of parts per million. All three natural radiation sources included in OSL calibration, including potassium (K), can be accurately measured and included in the age equation. Like the ICP samples, a homogenized pellet made from a

soil sample and one made directly from a portion of each sherd were tested using the XRF. Protocols followed for the sample preparation and analysis can be found in Appendix A. A record of the concentrations of U, Th, and K obtained through XRF analysis can be found in Tables 2 and 3. A complete protocol of how XRF analyses were conducted for this project can be found in Appendix E.

Site Analysis and Relevance

While the human occupation of the Soda Lake region extends far before the use of ceramic technologies (Warren 1984), this study is limited temporally to the Late Prehistoric period when ceramics were available and utilized by Mojave Desert peoples. This period is generally accepted to begin around cal A.D. 1100 and extends until European contact (Sutton et al. 2007). Of course the use of ceramics in the area extended well into the historic period as well. With few exceptions, the ceramics in this study complement the generally accepted knowledge of the region. This study, however, offers some much needed detail to the currently accepted ceramic chronology and sheds light on some of the smaller archaeological sites that have been largely ignored in the literature pertaining to the Mojave.

All the dates discussed in this study represent averages from multiple sub-samples created from each individual ceramic sherd. Between 2 and 5 aliquots were analyzed for each sherd, and the average of these dates is assumed to approximate the date of manufacture for that particular ceramic. Error terms are given in whole years throughout the discussion. A graph representing the ages and the error terms for the entire

assemblage is organized by site number in Figure 5. Also, a graphical representation for the ages of the sherds at each site can be found in Figure 6 through Figure 9. For a complete table of the dates from this study organized by site number, refer to Table 1.

Interestingly, this study draws attention to two distinct occupation periods marked by higher numbers of ceramics and which are marked in Figure 5. The first period, called occupation period A, seems to last from a little before A.D. 1200 to just after A.D. 1400 and all the localities examined contain ceramic samples from within this timeframe. A period of time with few ceramic samples separates occupation A from occupation B, which lasts from a little after A.D. 1600 until the mid-1800s. Only three of the five localities investigated have ceramics from occupation period B, and there are admittedly fewer ceramics from this period, but the clustering of ceramics within this time is dense enough to assume that this is a separate occupation. As pointed out in Chapter 2, the peoples of the Mojave Desert were most likely nomadic hunter-gatherers and so site abandonment and reoccupation would have been common as resources shifted from year to year. A prolonged site abandonment in the Soda Lake region, like the two century gap in pottery between A.D. 1400 to A.D. 1600, may have some far reaching implications for the local climate or environment that is beyond the scope of this study. It should be noted that intense natural fire, which are not unknown to the region, can affect luminescence dates. Far more data would need to be accumulated to provide evidence of large-scale wildfires in the past, which again is beyond the scope of this project. It is assumed that

all the dates associated with this Soda Lake assemblage to the human manufacture of each ceramic sample.

Site CA-SBR-3571

Site CA-SBR-3571 was one of the larger sites in the study and had the most OSL dated ceramics with a total of 13 dates generated. This site is a perfect example of a site used and reused during both occupation period A and occupation period B (Figure 6). The earliest date is approximately A.D. 1241 ± 40 while the latest dates are in the A.D. 1855 ± 16 range, a span of roughly 600 years. There seems to be a more continuous occupation during period A, before the 1400s, with 7 samples occurring during period A prior to A.D. 1405 ± 26. Five sherds fall within occupation period B, with only a single sherd representing the interim period. During the survey process, it was noted that several sherds had a unique grey colored fine-grained paste that is not common in the area (David Nichols, personal communication). Several of these sherds were dated (Sample #LB384, LB385, LB386, LB397) and established to be from the later occupation period B, almost exclusively from the 1800s. Though outside the typical geographical range, these sherds bare some resemblance to the Lower Colorado Buff-ware originally described by Schroeder (Schroeder 1958; Lyneis 1988) at least with respect to paste color and grain-size. The later period uses of this site may have coincided with a slight increase in the level of the perennial shallow waters that existed in the Soda Lake basin between the A.D. 1600s to the A.D. 1800s (Wells et al. 2003). It is possible that this area

and neighboring sites would have been along the shoreline, or in marshy areas between sand dunes at the time of human occupation during occupation period B.

Site CA-SBR-3570

The nearby site of CA-SBR-3570, which is significantly smaller than the previous site, had a smaller ceramic scatter on the surface and a total of 7 luminescence dates were recorded for the site. The time range of these ceramics is slightly narrower, between A.D. 1246 ± 33 and A.D. 1769 ± 17 spanning a little over 500 years. Five sherds came from occupation period A (Figure 7) between A.D. 1200 and A.D. 1400, and the site seems to be most heavily occupied during this time since only two sherds appear in occupation period B. Though close in proximity to site SBR-3571, none of the unique grey-pasted pottery from occupation period B was noted on the surface of this site. Sherds from SBR-3570 were nearer to the expected forms of pottery in the area, with a coarser paste nearer to a sandy buff color. Again, the major occupation seems to lean towards an earlier date within occupation period A, since 5 of the sherds are dated to A.D. 1325 ± 35 or before and no sherds represent the interim time between the two occupation periods.

Isolate Sherds on West Shore of Soda Lake

In the general vicinity of site SBR-3570 and SBR-3571, 3 isolate sherds unassociated with the sites were also recovered. One of the sherds (LB409) has a rather early date of A.D. 1353 ± 32, and falls within the parameters that define occupation period A (Figure 5). Another of the isolates (LB408) dates to A.D. 1596 ± 34. Finally, a

very unique sherd (LB403) with an obvious exterior slip and possible painted design and a small, partial drill hole gives a date of A.D.1560 ± 42. These last two isolates date to the interim period of lesser occupation, and proves that humans were present in the region even during this time period. None of these isolates are officially associated with any known deposit, but their location near the other sites is consistent with the presumption that this area was frequented by hunter-gatherers on their seasonal rounds over an extended period of history.

Site CA-SBR-5421

To the east of this area and closer to the current edge of the Soda Lake playa, the ceramic scatter at site CA-SBR-5421 yielded 6 luminescence dates. This more complex surface deposit included groundstone indicative of later period occupations during the initial field survey (Nichols, personal communication). Concurrent with this observation, the site has a heavier occupation at the end of occupation period B between the 1700s and 1800s. While a single early ceramic dates around A.D. 1371 ± 29, the other 5 ceramic dates range from A.D. 1703 ± 30 to A.D. 1864 ± 16. The majority of this assemblage was made up sherds of the fine, grey paste similar to the later ceramics of SBR-3571. In fact, with the exception of the very early ceramic (LB399) which is of a coarser buff colored paste, all the other ceramics tested from this site are similar to the fine grey paste sherds mentioned at the other site and that also occurred in occupation period B. The appearance of these similar ceramics at a rather narrow time range may point toward a regionally specific pottery type previously undescribed in the literature. It would be quite

significant if other sites with similar ceramics could be located and dated to a comparable time period in the central Mojave region.

Site CA-SBR-5417

Moving to the north, site CA-SBR-5417 is a rather expansive site with many component artifacts that yielded 9 ceramics dated OSL. The range of dates from SBR-5417 is relatively early when compared to the previously discussed sites and no samples from this site represent the later occupation period B. Here the range begins at A.D. 1010 ± 115 and extends until A.D. 1486 ± 142. Six of the samples fall roughly within occupation period A (Figure 9), even when their error terms are taken into account. Error terms for this group of ceramics are much higher than the others included in this study and this increase might be attributed to the use of LA-TOF-ICP-MS to calibrate these dates. Still, the fact that the human occupation of this site spanned centuries is a testament to both the antiquity of the site and its constant re-use by the local human population.

Site CA-SBR-1997

The final site, and by far the largest and most complex artifact scatter, the eastern site of CA-SBR-1997 yielded very few ceramics and only 2 were dated using OSL. Both of the ceramics dated from this site were relatively early, at A.D. 1232 ± 35 and A.D. 1358 ± 24, and fall within occupation period A. The ceramics collected from this site were of a very coarse paste and heavily tempered with coarse grained quartz particles. This expansive site had a large quantity of lithic material and was very well suited for an

analysis of flaked stone. The antiquity of this site probably far exceeds the ceramic dates presented here, however it is important to note that ceramic technology was in use at this site during its occupation. Also, the presence of this site on the playa shore, and the early use of ceramics, may shed light on the changing climate within the region upon further study. Overall, the Soda Lake has a very long history of human occupation which is supported by the ceramic dates provided in this study.

Precision and Accuracy

As with any study that discusses age determination by various physical and chemical properties, it is important to be able to judge the quality of any age offered. The criteria that indicate the reliability of any particular date are the accuracy and the precision. Accuracy deals with the "degree of correspondence between the true age of a sample and that obtained by the dating process" (Walker 2005:5). Essentially it is a gauge of the bias within the offered dates. Alternatively, precision refers to the "statistical uncertainty that is associated with any physical or chemical analysis that is used as a basis for determining age" (Walker 2005:6). This term relates to the replicability of any given age over several tests.

The software called *Analyst*, created for use with the Risø TL/OSL-DA-15 combined TL/OSL reader, is programmed to estimate both the precision and accuracy of the dates produced by this study (Duller 2007). Since each date given for a particular sherd in this study represents an average of multiple aliquots (sub-samples) from that sherd, it is important to asses the reliability of measurements for each tested aliquot. Two

plots were created for each sherd to visually represent the cumulative measurements of the aliquots and to asses both their precision and accuracy.

One plot used to measure the reliability of a group of aliquots is the *radial plot*. The plot is essentially a two-dimensional one, with the precision of an individual data point plotted on the x-axis, and the difference between the central value for that point and some mean value for the whole population plotted on the y-axis (Duller 2007:34). The right side of the plot shows the measured paleodose (D_e), while the left side y-axis expresses each point in "the number of standard deviations of that individual data point away from the mean value for the population" (Duller 2007:34). A true normal distribution within a group of samples would show about 95% of the data points to fall within two standard deviations of the mean (Duller 2007:34). To continue using the example of sample LB395 in Figure 11, approximately 80% of the aliquots fall within two sigma or standard deviations of the average which is used to create the final OSL date. The aliquots within this two sigma standard are filled in red, while points falling outside the standard are white. Over all the plots, the more points within the two sigma range, the more precise a given OSL can be said to be.

Another plot, called a *weighted histogram*, has been created for each sherd that can help illustrate both the precision and accuracy of a given OSL date. This plot represents each data point as a curve, whose mid-point is the value being plotted, and whose width is related to the precision with which the value is known (Duller 2007:33). Generally a less precise value is represented by a low, flat curve, while a precisely known

value is shown as a high, narrow curve (Duller 2007:33). The line that goes through each point represents the range of dose signal attributed to the single aliquot, so generally is shows the signal scatter within each sub-sample. The curve drawn on the plot is a representation of the entire range for a single sherd as averaged among the aliquots. The high curve represented in Figure 12 shows that there is a high precision for the OSL date given for sample LB395, while the width of the curve shows the full range of dose signal measured in the testing. The mean, shown along the x-axis in each plot, is the numerical mean given for the dose signal given in Gy. By comparing the mean signal to the signals encompassed in the full width of the curve, one can visually asses the accuracy of the mean signal used to calculate the OSL date. For both radial plots and weighted histograms of each sherd, see Appendix C.

The *Analyst* software offers another way of measuring the accuracy and error of each aliquot. As can be seen in a screen capture of the *Analyst* program while LB395 was analyzed (Figure 10). Parameters can be set to assess and mark any aliquots with error over a pre-determined percentage when reading the Gy signal (Duller 2007:35). The software can estimate the ability of the luminescence reader to measure an OSL signal accurately and can assess the effects of the natural luminescence scatter within each aliquot (Duller 2007:35). In Appendix A, aliquots that had an error term over 10% are indicated with double asterisks (**). Aliquots marked "rejected" were not included in the final generated date because they had error terms over 10% and were outside the two sigma range on the radial plot. With these corrections and this information concerning

precision and accuracy, the reliability of the OSL dates presented in this study can be supported.

Summary

With the great antiquity of human occupation in the Mojave Desert a well established fact, it has been generally accepted that ceramic use in the Mojave began around cal A.D. 1100 (Sutton et al. 2007) though some relative dates for ceramics have been assumed to originate before A.D. 800 (Schroeder 1958: Warren 1984). Figure 5 compares the ages of all the ceramics dated in this study between the different sites and suggests two distinct occupation periods. The graph marks each average date of manufacture with a small square, while the line indicates the extent of the error term (Figure 5). The longer the line, the more time the error term represents. The earliest dates from this study of Soda Lake ceramics are very near to the generally accepted A.D. 1100 date. Taken as a whole, the data seems to show a distinctive human presence between A.D. 1200 to A.D. 1400 called occupation period A for the purposes of this study, as well as a lighter but still apparent occupation between A.D. 1600 and A.D. 1800 called occupation period B. Despite its larger margins of error, site SBR-5417 seems to be an older site whose ceramics fall mostly within period A and that was not heavily utilized after A.D. 1600. In contrast, SBR-5421 seems to be a decidedly later site with only minimal evidence of occupation prior to A.D. 1400 and only a single ceramic sample within occupation period A. This study clearly demonstrates the prolonged

human occupation of the Soda Lake region and is a testament to the value of ceramic studies in the Mojave Desert.

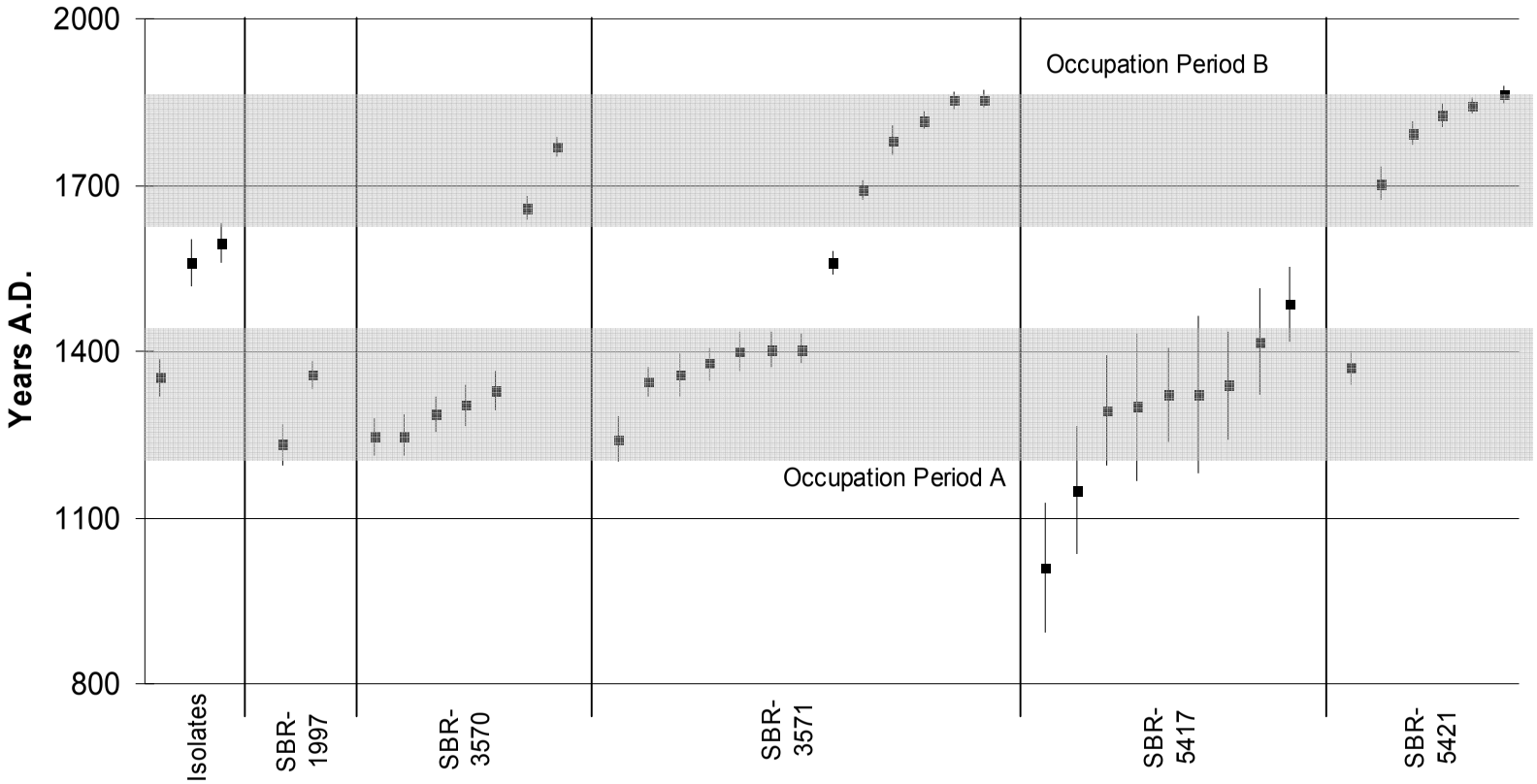


FIGURE 5. Temporal comparison of whole assemblage. Each square indicates the average age of a single ceramic sample and the line represents the error term for that sample. The two occupation periods defined by this study are marked.

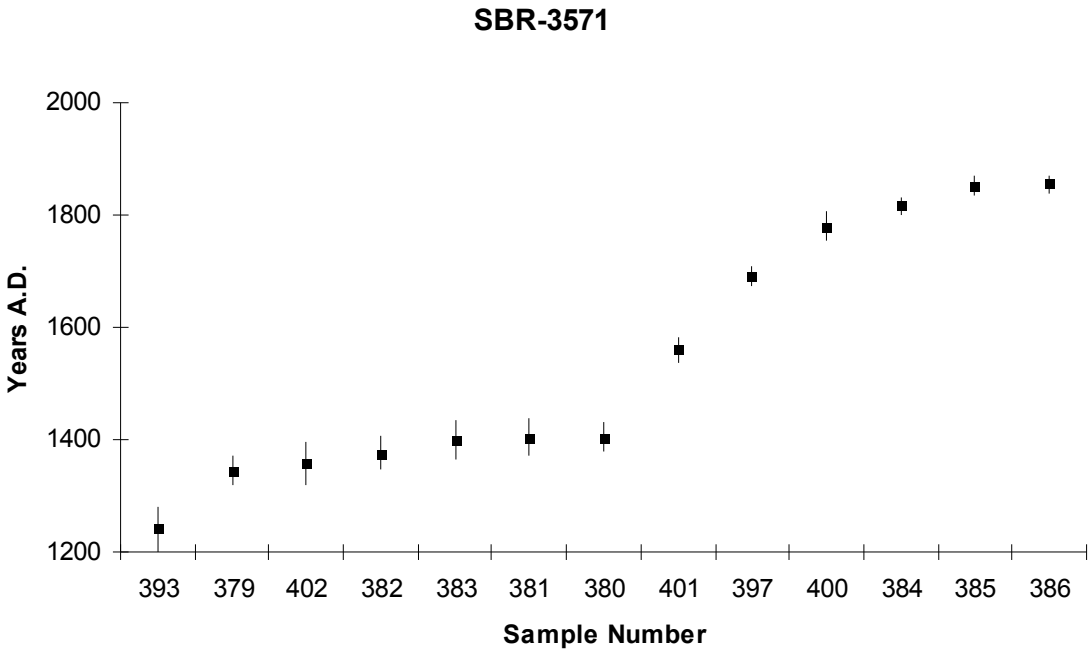


FIGURE 6: Temporal range for site SBR-3571.

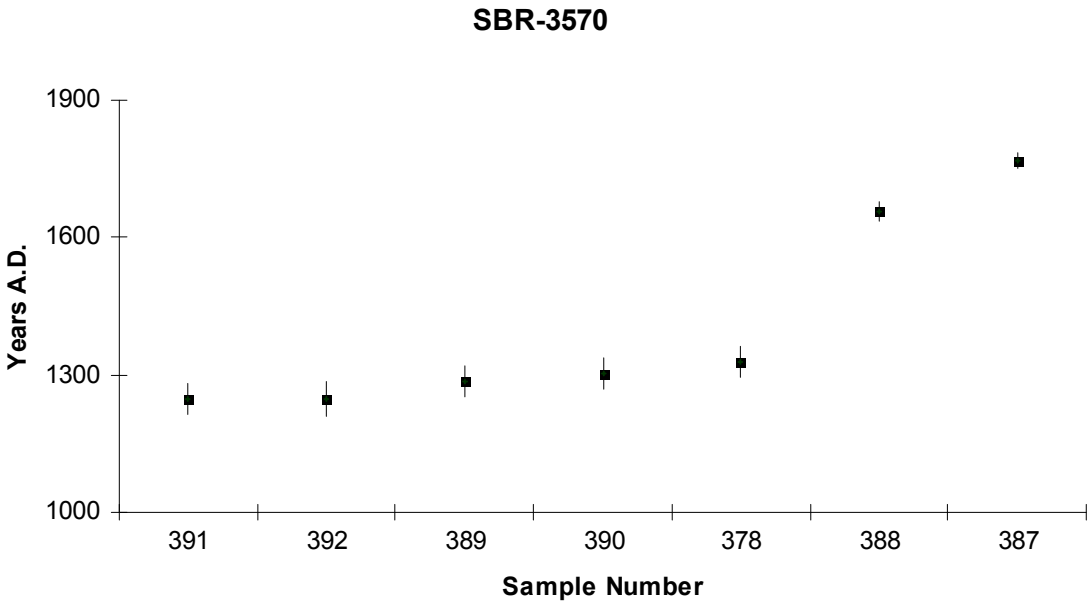


FIGURE 7: Temporal range for site SBR-3570.

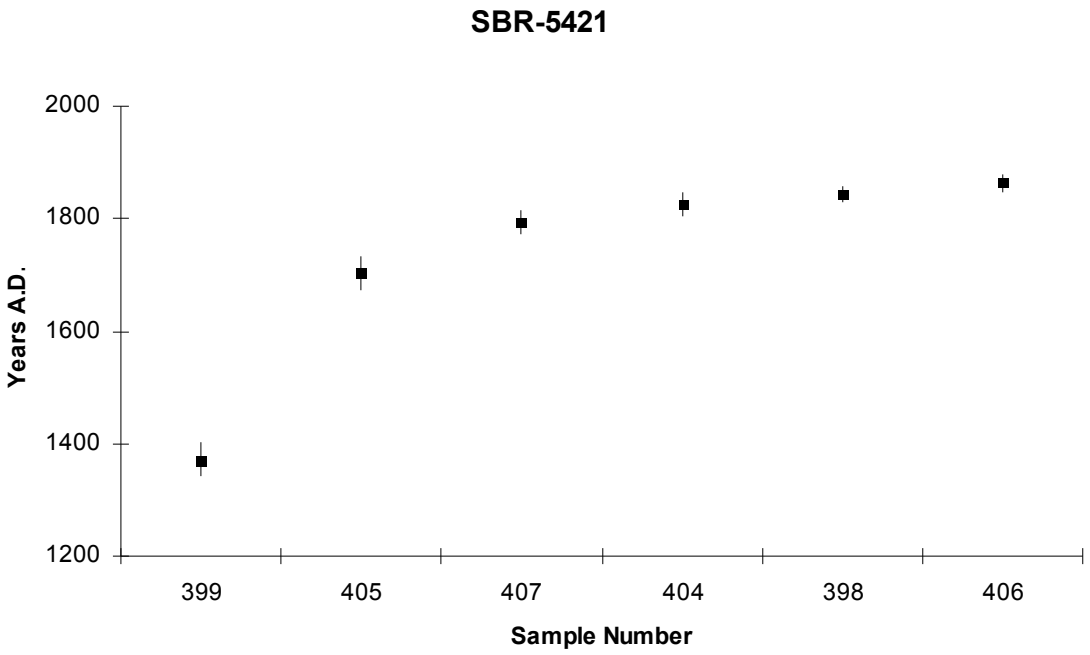


FIGURE 8: Temporal range for site SBR-5421.

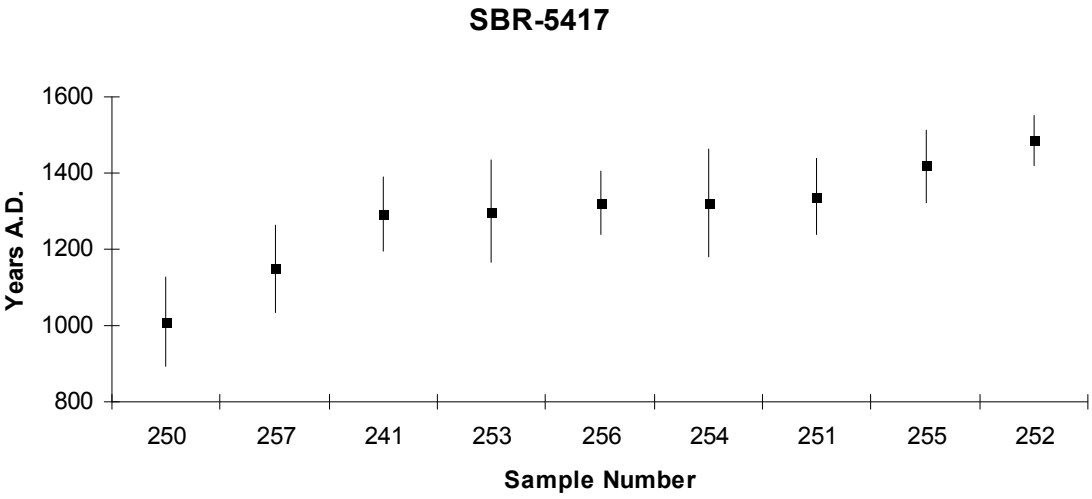


FIGURE 9: Temporal range for site SBR-5417.

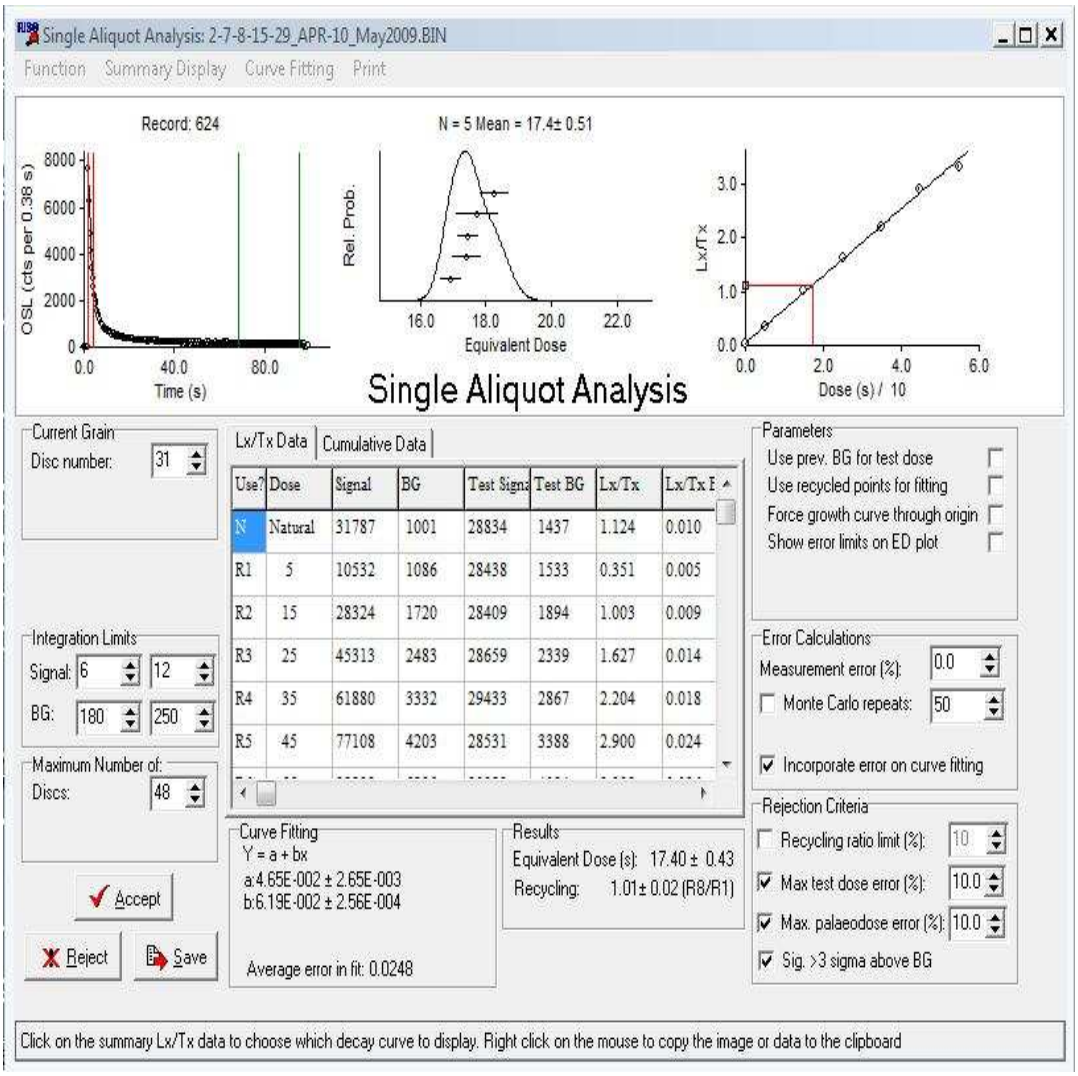


FIGURE 10: Screen-capture of *Analyst* software.

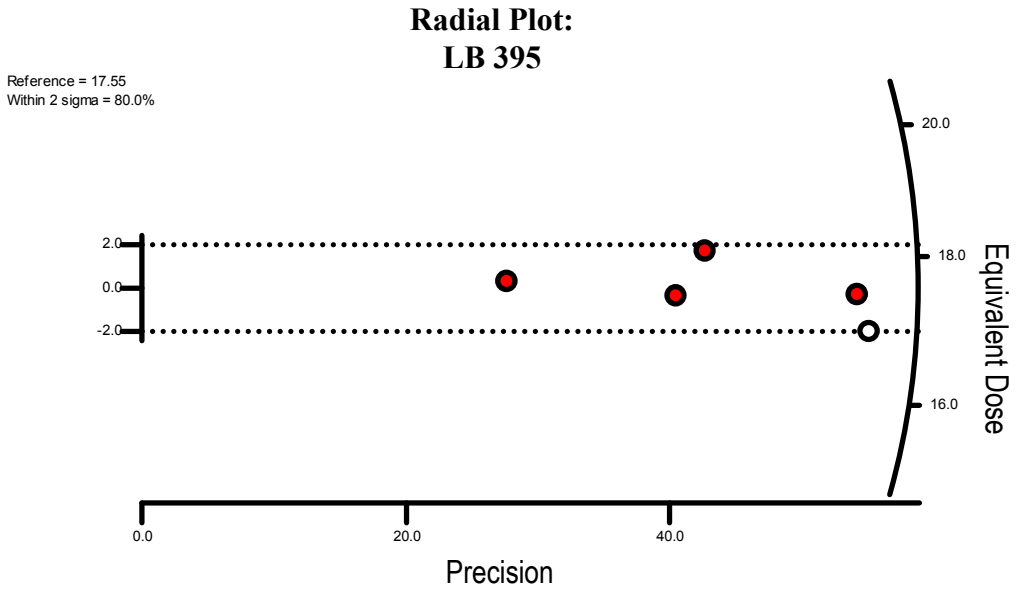


FIGURE 11: Radial plot for LB 395. Each point represents a single aliquot and all red points are within 2-sigmas of the average, indicating a high precision for this sample as a whole.

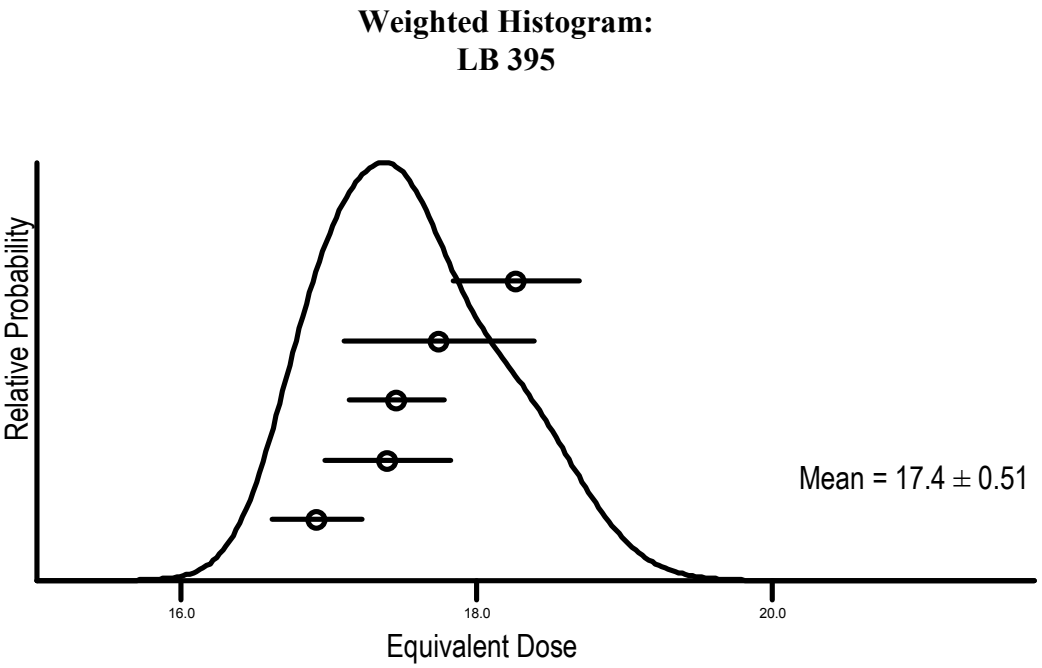


FIGURE 12: Weighted Histogram for LB 395. The curve represents the full range of a single sample, and this high narrow curve also shows the samples high precision. See Appendix C for graphs of each sample.

TABLE 1. Average OSL Dates

Site Number	LB Sample Number	Year (AD)	Error
ISO	409 Average	1352	32.71
ISO	403 Average	1560	42.80
ISO	408 Average	1596	34.92
SBR-1997	394 Average	1232	35.79
SBR-1997	395 Average	1358	24.52
SBR-3570	391 Average	1246	33.90
SBR-3570	392 Average	1248	38.21
SBR-3570	389 Average	1286	33.00
SBR-3570	390 Average	1303	35.78
SBR-3570	378 Average	1328	35.35
SBR-3570	388 Average	1658	21.03
SBR-3570	387 Average	1769	17.62
SBR-3571	393 Average	1241	40.64
SBR-3571	379 Average	1345	27.35
SBR-3571	402 Average	1358	39.16
SBR-3571	382 Average	1377	29.69
SBR-3571	383 Average	1399	36.21
SBR-3571	381 Average	1404	32.52
SBR-3571	380 Average	1405	26.25
SBR-3571	401 Average	1560	22.41
SBR-3571	397 Average	1692	16.73
SBR-3571	400 Average	1780	26.45
SBR-3571	384 Average	1817	16.23
SBR-3571	385 Average	1853	16.13
SBR-3571	386 Average	1855	16.22
SBR-5417	250 Average	1010	115.93
SBR-5417	257 Average	1150	115.00
SBR-5417	251 Average	1221	98.82
SBR-5417	241 Average	1294	98.53
SBR-5417	253 Average	1300	133.61
SBR-5417	256 Average	1322	83.93
SBR-5417	255 Average	1418	95.25
SBR-5417	252 Average	1486	66.78
SBR-5417	254 Average	1486	142.93

TABLE 1. Continued

Site Number	LB Sample Number	Year (AD)	Error
SBR-5421	399 Average	1371	29.93
SBR-5421	405 Average	1703	30.88
SBR-5421	407 Average	1795	21.45
SBR-5421	404 Average	1825	20.18
SBR-5421	398 Average	1842	14.55
SBR-5421	406 Average	1864	16.41

Note. OSL dates shown in A.D. for each sherd and organized by archaeological site number.

TABLE 2. XRF Radiation Samples

Radiation Sample Number	K (ppm)	Th	U
LB_378	19,250.87	3.875219	2.02001
LB_379	16,163.82	2.106177	2.080078
LB_380	16,164.82	2.106177	2.080078
LB_381	18,173.70	4.18845	1.982194
LB_382	18,098.77	3.063626	2.158879
LB_383	18,769.10	3.359789	1.864736
LB_384	16,706.08	3.966429	1.94702
LB_385	16,707.08	3.966429	1.94702
LB_386	16,708.08	3.966429	1.94702
LB_387	17,653.01	4.618228	1.830824
LB_388	17,654.01	4.618228	1.830824
LB_389	18,098.77	3.551244	1.729048
LB_390	18,099.77	3.551244	1.729048
LB_391	18,100.77	3.551244	1.729048
LB_392	18,098.77	3.063626	2.158879
LB_393	16,053.23	3.347236	2.062861
LB_394	19,717.69	4.313966	1.560608
LB_395	19,718.69	4.313966	1.560608
LB_397	19,400.76	2.980384	1.990673
LB_398	16,452.33	2.862615	2.047077
LB_399	19,957.38	2.882943	1.912896
LB_400	22,537.15	4.252328	1.782741
LB_401	23,228.13	4.252328	1.782741
LB_402	26,789.27	2.498459	1.943091
LB_403	24,167.97	3.61657	1.582777
LB_404	22,601.51	3.373844	2.068402
LB_405	16,452.33	2.862615	2.047077
LB_406	22,133.71	3.208665	2.008756
LB_407	19,101.29	3.372321	1.926901
LB_408	23,763.95	3.221998	2.024895
LB_409	19,621.45	2.98285	2.096428

Note. Potassium (K), Thorium (Th) and Uranium (U) elemental concentrations in parts per million (ppm) resulting from XRF analysis of soil sample surrounding each ceramic sample.

TABLE 3. XRF Dosimetry Samples

Dosimetry Sample Number	K	Th	U
LB_378	17,368.64	5.288498615	2.019585
LB_379	20,163.03	4.431536488	1.488441
LB_380	23,002.41	5.378414249	1.716002
LB_381	19,435.34	4.857761256	2.059479
LB_382	20,959.82	4.074623116	2.030641
LB_383	18,964.01	6.979681268	1.002698
LB_384	21,095.75	4.689592626	1.725409
LB_385	21,142.96	4.827467226	1.635273
LB_386	18,927.37	4.897109018	1.495939
LB_387	26,070.46	4.450155054	1.857461
LB_388	17,588.91	5.423239863	1.7212
LB_389	22,785.59	3.701221736	2.070585
LB_390	20,801.47	2.173048496	2.138745
LB_391	20,577.18	4.454486641	1.918128
LB_392	18,047.91	4.36220941	2.049943
LB_393	16,889.39	2.954580088	2.115327
LB_394	21,934.38	7.676710171	0.58968
LB_395	22,758.50	7.672838386	0.344463
LB_397	21,163.90	3.508306884	2.097189
LB_398	20,727.23	3.770921678	1.895174
LB_399	19,957.38	4.382640064	1.999923
LB_400	23,127.30	4.294417432	1.694858
LB_401	20,878.73	4.313049772	1.893278
LB_402	19,855.81	4.348591306	1.956342
LB_403	12,617.42	4.430295126	2.008872
LB_404	20,522.61	3.276992716	1.954971
LB_405	19,664.48	4.28212019	1.998077
LB_406	21,526.09	4.063018143	1.851545
LB_407	22,400.48	4.786236019	1.672506
LB_408	20,783.76	6.296708108	1.550656
LB_409	19,978.19	4.491558924	2.24343

Note. Potassium (K), Thorium (Th) and Uranium (U) elemental concentrations in parts per million (ppm) resulting from XRF analysis of sample sherd for dosimetric purposes.

TABLE 4. ICP-MS Radiation Samples

Radiation Sample Number	K	K (%)	Th	U
LB_241-Av	3843.60	4.63	5.11	0.13
LB_250-Av	6244.98	7.52	4.80	0.14
LB_251-Av	7705.70	9.28	14.41	0.20
LB_252-Av	8632.25	10.40	3.18	0.22
LB_253-Av	5276.00	6.36	3.12	0.12
LB_254-Av	4182.23	5.04	18.97	0.26
LB_255-Av	3493.39	4.21	4.00	0.12
LB_256-Av	20252.40	24.40	8.88	0.17
LB_257-Av	4724.25	5.69	6.41	0.15

Note. Potassium (K), Thorium (Th) and Uranium (U) elemental concentrations in parts per million (ppm) resulting from ICP-MS analysis of soil sample surrounding each ceramic sample.

TABLE 5. ICP-MS Dosimetry Samples

Dosimetry Sample Number	K	K (%)	Th	U
LB_241-Av	11622.20	14.00	17.77	0.83
LB_250-Av	7516.12	9.05	5.61	0.41
LB_251-Av	8755.43	10.55	6.75	0.58
LB_252-Av	16880.40	20.34	11.46	0.78
LB_253-Av	9339.78	11.25	10.55	0.68
LB_254-Av	13711.59	16.52	27.87	1.06
LB_255-Av	5104.08	6.15	4.50	0.28
LB_256-Av	8451.78	10.18	11.83	0.62
LB_257-Av	18818.95	22.67	27.61	1.18

Note. Potassium (K), Thorium (Th) and Uranium (U) elemental concentrations in parts per million (ppm) resulting from ICP-MS analysis of sample sherd for dosimetric purposes.

CHAPTER 6

FUTURE RESEARCH

Establishing a chronology allows for a multitude of questions and observations to be made concerning various attributes of the examined artifacts that can now be measured through the time dimension. One of the earliest and most inspired observations made by archaeologists in North America was the potential to explain not only differences in the archaeological record, but changes in the record over time (Lyman et al. 1997). Past ceramic studies have proven particularly useful in describing the change in the archaeological record through time (see Eerkens and Lipo 2005; Eerkens et al. 2002), and have even offered explanations for the changes observed (see Feathers 2006). However, it is chronology which is the most important aspect of any archaeological study. Chronology is the basis of measuring many variable parts of the archaeological record, like the changes in ceramic technology throughout prehistory. This ceramic study, though limited in both sample size and geographical scope, offers a starting point for understanding changes in the material record of the Mojave Desert region through its long history of human occupation.

Changing Ceramic Attributes

A recent study of pottery from Death Valley and Owens Valley (Eerkens and Lipo 2008) shows a temporal trend in the thickness of sherds in these regions. Studies in the ceramics of both regions show a trend toward thinner pottery as time progresses

toward the present. Especially in the Owens Valley, measurements of sherd thickness decrease steeply over time when compared to associated radiocarbon data as well as to luminescence dates produced much the same way as dates from this study (Eerkens and Lipo 2008). Also, this study shows that ceramic technology in the Owens Valley developed around A.D. 1000, some 380 years before to similar technologies in Death Valley. Further analyses showed that the density of organic material within the ceramic pastes and the amount of mica in the sherds also followed similar temporal trends between the regions (Eerkens and Lipo 2008). Based on these concurrent trends over several attributes, the study suggests that there is a close relationship between the ceramic technologies of the Owens Valley and Death Valley (Eerkens and Lipo 2008).

On its own, the observation of a temporal trend in sherd thickness offers little in the way of satisfying and interesting archaeological information. While the scope of this study in the Mojave does not encompass an explanation for the changes in this pottery, ceramic studies in the Owens and Death Valleys can render a similar analysis of the Soda Lake assemblage most intriguing. The sherds from the Soda Lake study date at their earliest to A.D. 1010, with a fair number of sherds occurring between A.D. 1200 and A.D. 1400 in what has been termed occupation period A in this study. Even within the small ceramic assemblage described in this study, it is possible conduct analyses that will illuminate some attributes that change through time. With a chronology of this ceramic collection in place, other observed characteristics of the sherds can be assessed over a time scale. Even a simple comparison of the thickness of each sherd generates some intriguing temporal trends. A graph of the whole assemblage (Figure 13) reveals a slight, but measurable, increase in the thickness of the ceramics over time. The R^2 value marked

on the graph indicates the strength of the correlation. Where a 1.0 value would be a perfect correlation between advancing time and thickening pottery, the R^2 value of 0.1 in the graph could indicate a weak increase in ceramic thickness over time. In order to make this a more sound statistical, a much larger sample size would need to be analyzed.

When each of the defined occupation periods are examined on their own, more detailed comparisons can be made. For instance, a graph representing the thickness change during occupation period A (Figure 14) shows a more pronounced increase in the thickness of sherds over time with an R^2 value of roughly 0.15. Though the later period has fewer samples, occupation period B also demonstrates a slight increase in thickness of ceramic sherds over time as well and has an R^2 value of about 0.16 (Figure 15). Site SBR-3571, which boasts the most dated samples of any site in this study, has the steepest increase in thickness over the 700 year occupation measured (Figure 16). The relatively high R^2 value of 0.3 shows a close correlation between ceramic thickness and advancing time over all the sherds. However, this site had the most dated samples associated with it and it had a high proportion of late ceramics that steepened the regression line in the chart. Graphing each occupation period separately within the SBR-3571 samples shows that the thickening trend holds true for both occupation period A and B (Figure 17 and Figure 18), though Figure 18 is skewed by a single thin and early ceramic from occupation period B. The far lower R^2 value of 0.05 shown in Figure 21 is due in part to the fewer dated samples, but the fact that the thickening trend persists even in this smaller site is a testament to the validity of the observation. Indeed, each of the other 3 sites proves this increase in ceramic thickness over time to varying degrees (Figure 19 – 21).

Since Death Valley lays to the south of Owens Valley and north of the Soda Lake region, effectively sandwiched between the two, the disparity in temporal and attribute trends is surprising. Coupled with the opposing observations on trends in thickness from the Eerkens and Lipo (2008) study, this study suggests that the Soda Lake ceramic assemblage is not as closely related to the Owens Valley technology as their Death Valley neighbors. It would seem that the ceramic making peoples of Soda Lake, and possibly the central Mojave, were not getting their ideas about ceramic technology from the Owens Valley or from their closer neighbors in Death Valley. The Eerkens and Lipo (2008) study argues for a close relationship between the Owens Valley and Death Valley, specifically where ceramic technologies are concerned. The fact that this study shows a relatively large number of sherds from a time period before ceramic technology took hold in Death Valley would seem to preclude them as possible instigators for the technology. Other sources for this kind of technology must be investigated, perhaps the Colorado River basin or southern Nevada area of the Great Basin. Furthermore, the close relationship between the Death Valley and Owens Valley ceramics that seems to exclude Soda Lake indicates that there was some other progenitor for the Mojave ceramic technology. This raises the question, who was making pottery similar to the Soda Lake assemblage and where were they from?

If all of this information can be gleaned from a simple two-dimensional study between thickness and time, comparing other attributes will only add to the understanding of ceramic technology throughout the region. Indeed, the Owens and Death Valleys study makes temporal comparisons to the amount of organic temper in the ceramics, the percent of exterior surface smoothness, and the amount of mica inclusions

(Eerkens and Lipo 2008). Various trends are evident, all generally consistent with the hypothesis that these two areas were closely connected in ceramic technology (Eerkens and Lipo). The Soda Lake assemblage described in this study could easily be measured for the same attributes in order to better reveal the relationship between these three regions. Also, the study area could be greatly expanded to see if the temporal trends in the Soda Lake area hold true for the entire central Mojave.

Ceramic Sourcing

Sourcing has been another important method of defining the relationships between ceramic technologies from different regions, and has proved extremely successful in a number of studies world wide (Neff 1996; Blomster et al. 2005; Eerkens et al. 2002, Hildebrand et al. 2002). The possibility of understanding past human mobility, interaction, and exchange are some of the most fascinating aspects of ceramic sourcing projects. This has led ceramic sourcing to become an increasingly utilized method for examining questions about prehistoric human interaction and exchange of ideas. However, ceramic typologies usually based on external stylistic elements have often been the root of ceramic sourcing studies (Eerkens et al. 2002:203). Areas like the Mojave are often overlooked because of their undecorated, outwardly similar ceramic remains.

But it is areas like the Mojave, and areas with seemingly homogenous ceramic "types," that could be most benefited by a better understanding of ceramic sources. As is made evident in a study by Eerkens et al. (2002) traditional ceramic typologies based on outwardly visible attributes failed in the Great Basin region of North America mainly due to the lack of decorative designs and the short time-depth of ceramics in the area. The

Eerkens et al. (2002) study used Instrumental Neutron Activation Analysis (INAA) to chemically characterize a number of raw clay samples from around the Great Basin and compared them to a collection of some 340 sherds from various archaeological sites. Based on measurements of a few attributes of each sherd compared to the chemical data, the study was able to conclude that most pottery in the Great Basin was locally produced and used (Eerkens et al. 2002:220). Also, it was noted that non-local pots were not haphazardly distributed through the archaeological record but instead seem to be related to differing precipitation patterns between region, and thus pots seem to be traded more often between areas with dissimilar environmental conditions (Eerkens et al. 2002:220). A pattern like this can suggest that peoples residing in the Great Basin were trading with peoples outside their region, or more probably that Great Basin peoples were moving around to take advantage of various "buffer" zones and leaving their pottery behind as they did so (Eerkens et al. 2002:221).

Similarly, sourcing projects in the southern reaches of the Mojave Desert have proven successful in cataloging possible trading patterns or even population movements across the California landscape (Hildebrand et al. 2002). Neutron Activation Analyses (NAA) and petrographic analyses performed on sherds from both desert and coastal regions of California showed that while ceramic sherds found in the desert had their source clays in the desert, some coastal regions had potteries that originated from the deserts (Hildebrand et al. 2002:136-137). A fresh understanding of the importance of the Imperial Valley and the southern Mojave was created by this Hildebrand et al. (2002) study, and as more data is collected the relationship between coastal and desert peoples in prehistoric California may become clear.

To complete the picture of California prehistory in the deserts, a better attempt to understand the central Mojave must be undertaken. Though costly in time, labor, and monetary resources, the central Mojave region that includes Soda Lake would greatly benefit from a ceramic sourcing project similar to Eerkens et al (2002) and Hildebrand et al. (2002). With the beginnings of a chronology generated in this study, a far better understanding of the range of mobility and possible exchange of Mojave Desert peoples could be made based on ceramic analyses. Further, with an established ceramic chronology, knowledge of the changing clay sources and ceramics could be made through time. Already a possible temporal group of the fine grey pasted ceramics found at CA-SBR-3571 has emerged through this analysis. It would be interesting to correlate this potential group to a raw clay source, discern whether these ceramics are local or imported, and gain better data on when these similar ceramics emerged.

Cultural replacement is an ever tempting explanation when dealing with artifacts that do not fit the expected forms (Feathers 2006). However, it is important to avoid any attempts at "voodoo" archaeology (Gee 1999:131) where conjectures about Lower Colorado or Patayan cultures (Colton 1945) moved in to replace more local or earlier cultures are used to explain the archaeological record. Rather, any further study of this ceramic assemblage from the Soda Lake region should be limited to an analysis of the evidence in hand, namely, the ceramic sherds themselves.

Conclusion

The Mojave Desert region has suffered a similar neglect from the archaeological community to many other regions that have outwardly indistinct and undecorated pottery styles. However, as increasing advances are made in analytical techniques and research

methods, one can hope that the Mojave Desert will gain more attention from scholars of archaeological ceramics in North America. The chronology offered in this study provides evidence the long complex history of the Soda Lake region in the central Mojave Desert. It should be understood that the ceramics in this study, as with every archaeological assemblage of any kind, are but a "snapshot" (Lyman et al. 1997:93) of the full variation that defines the archaeological record. These few ceramics collected from the surface of Soda Lake do not, and cannot, illuminate the entire complex history of human occupation in the Mojave Desert. But with careful examinations of the variability in ceramic attributes over time, it will be possible to better understand the mobility, technological advances, and the transmission of ideas within Mojave Desert ceramics and the potters who created them.

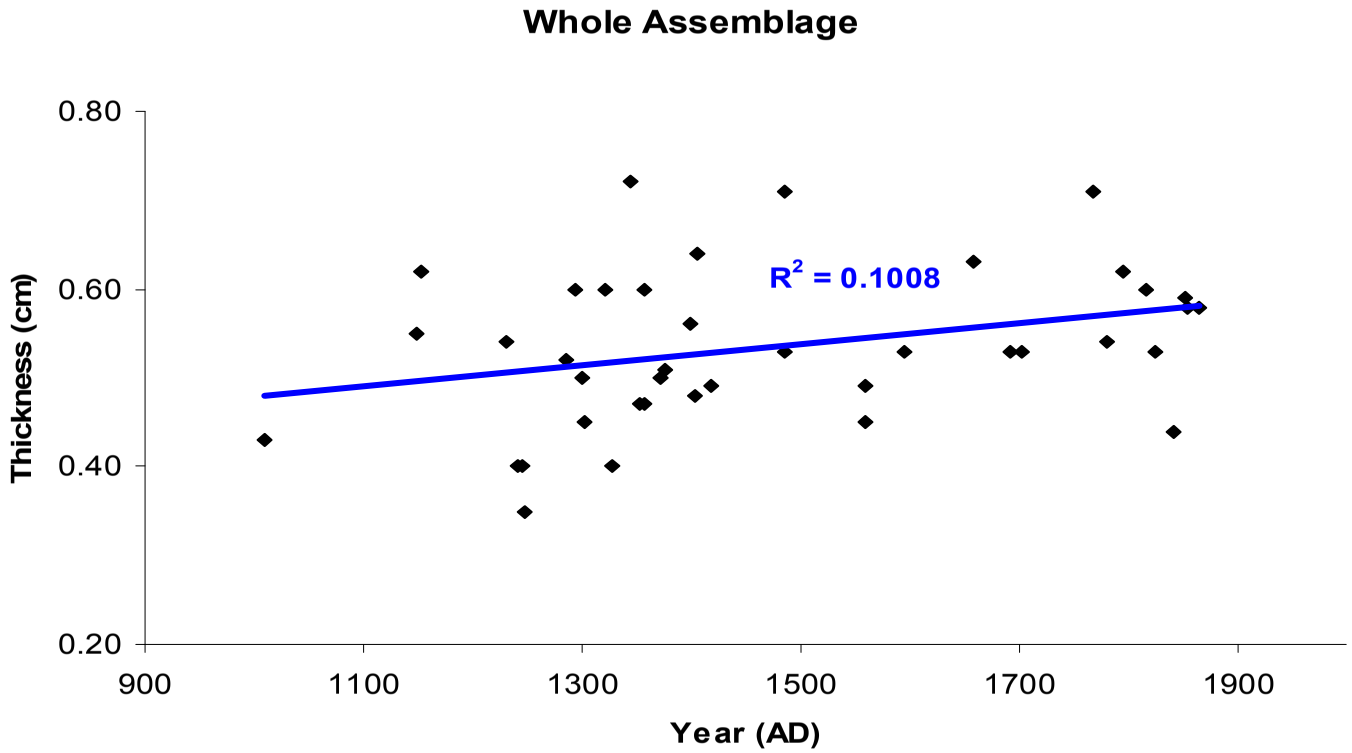


FIGURE 13. Thickness comparison of entire assemblage. Note that there is a mild thickening trend in this assemblage as time progresses towards the present.

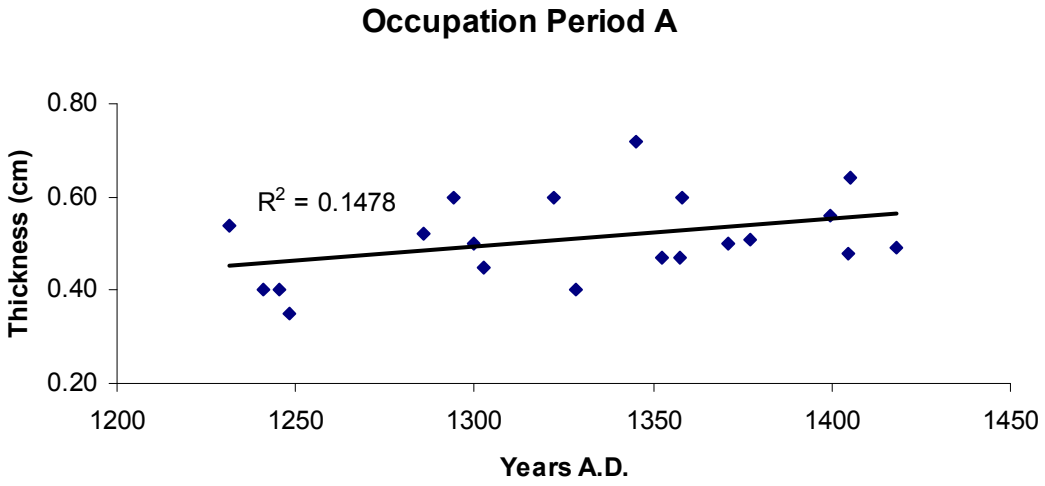


FIGURE 14. Thickness comparison of occupation period A. The period of higher occupation between roughly A.D. 1200 and A.D. 1400 shows this thickening trend again.

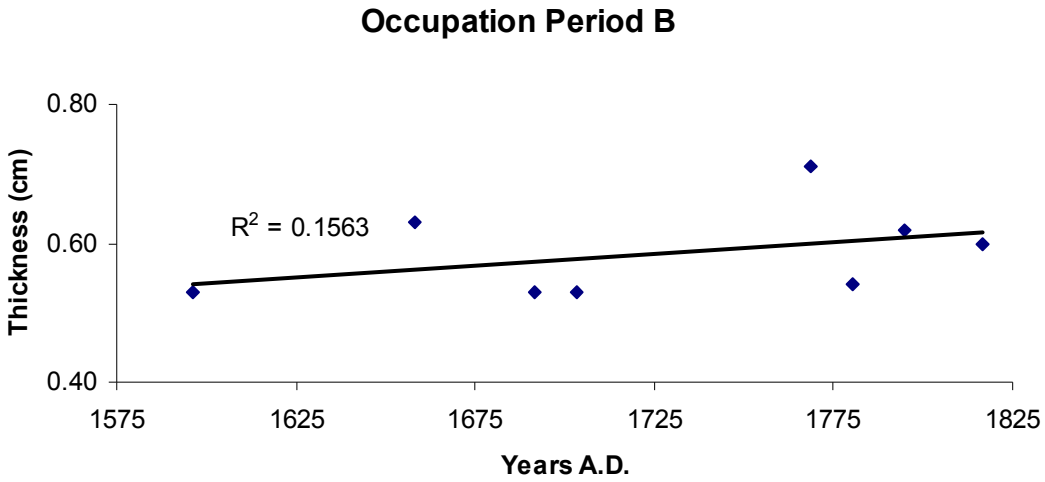


FIGURE 15. Thickness comparison of occupation period B. The later occupation period between A.D. 1600 and A.D. 1800 also shows also shows a thickening trend.

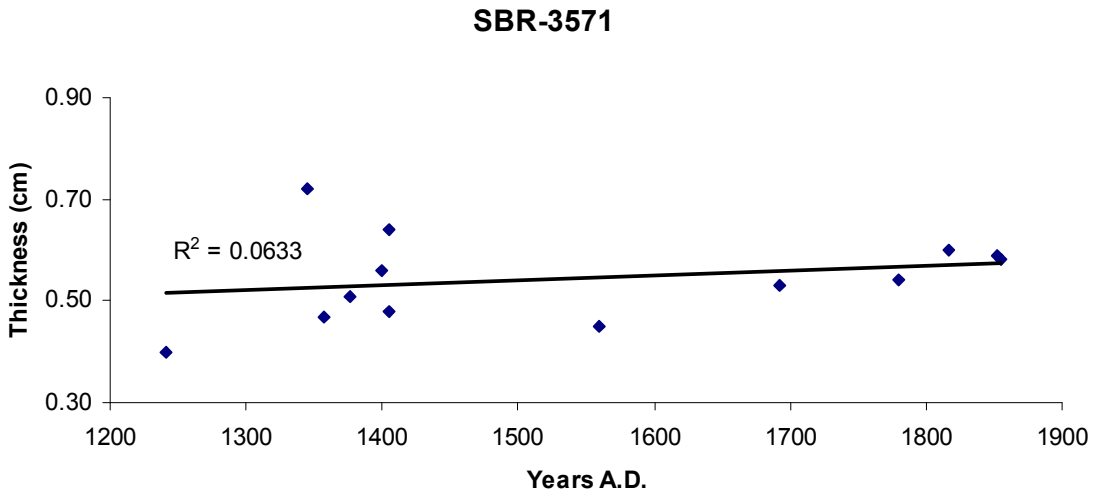


FIGURE 16. Thickness comparison of samples from site SBR-3571.

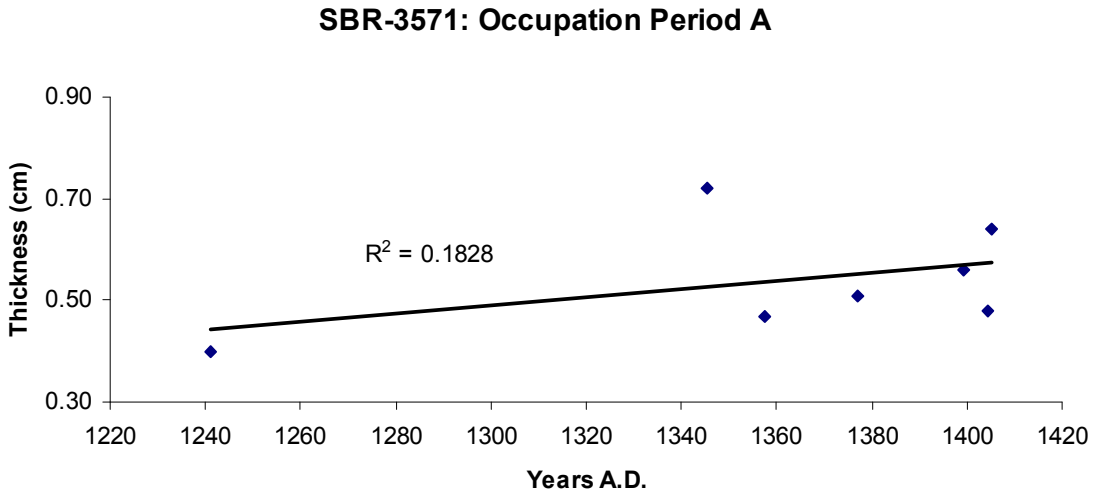


FIGURE 17. Thickness comparison of samples from occupation period A of site SBR-3571.

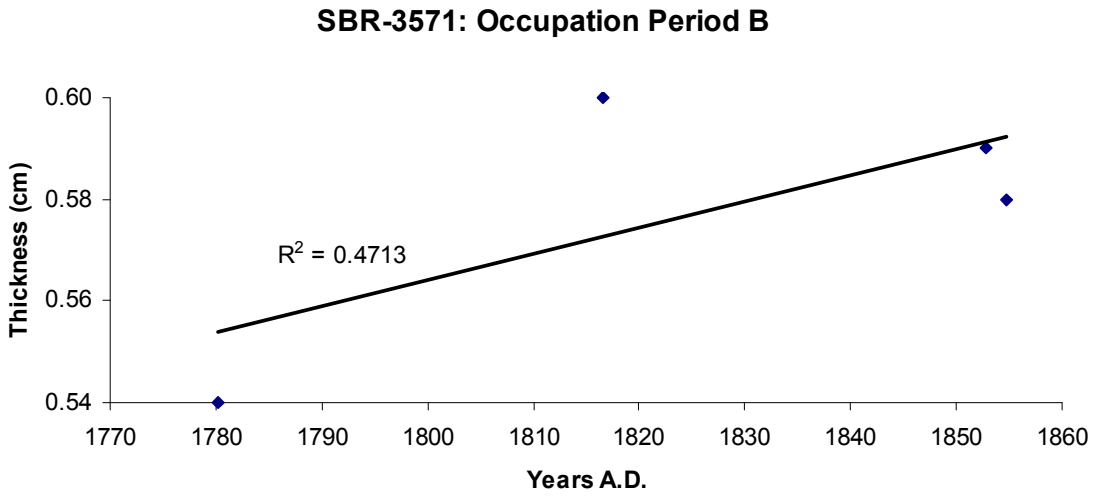


FIGURE 18. Thickness comparison of samples from occupation period B of SBR-3571. The steep trend here is cause by the single early sherd that does not fit the general trend.

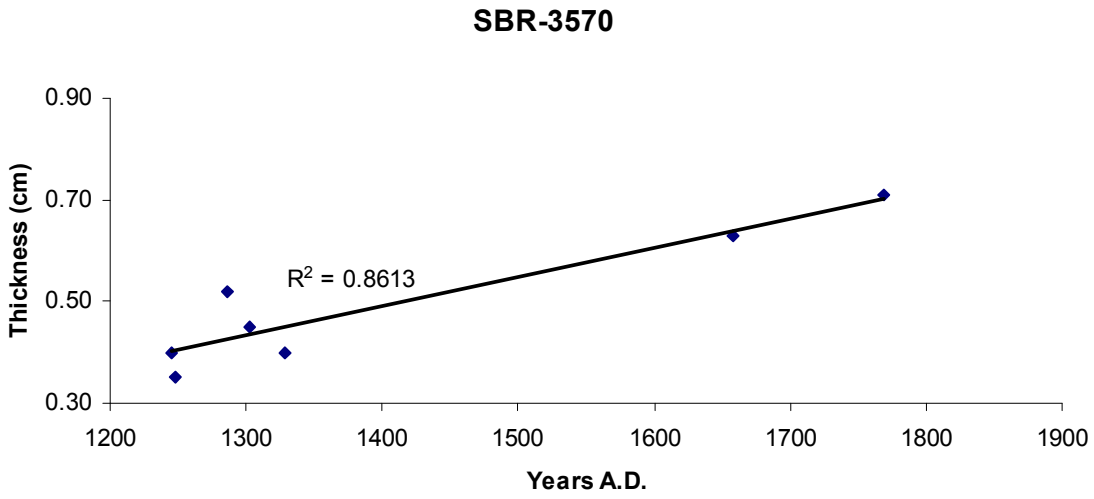


FIGURE 19. Thickness comparison of samples from site SBR-3570.

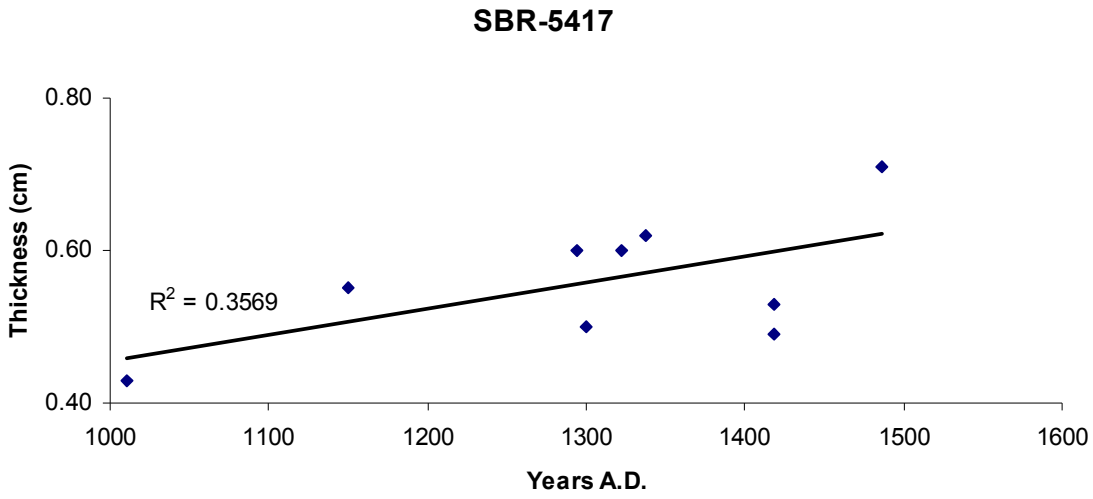


FIGURE 20. Thickness comparison of samples from site SBR-5417.

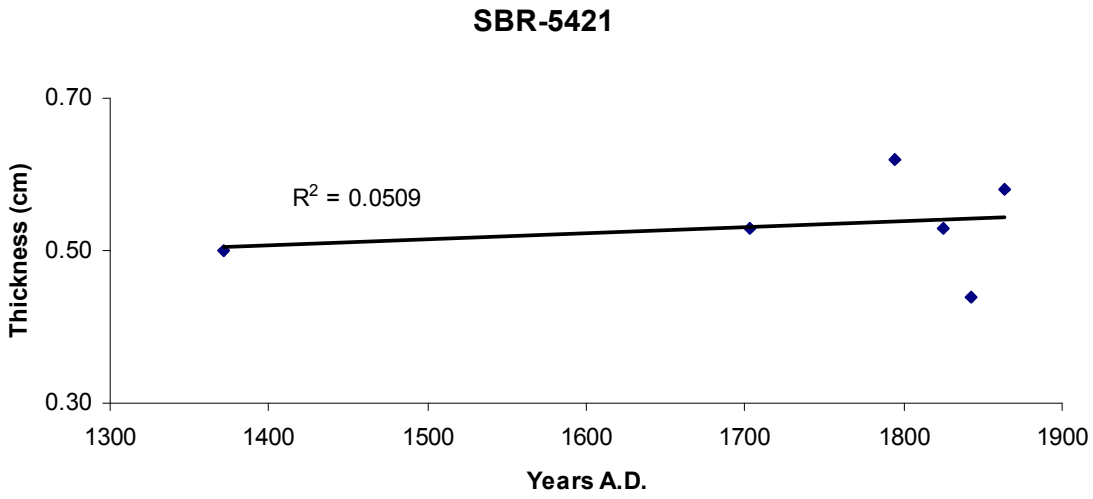


FIGURE 21. Thickness comparison of samples from site SBR-5421.

APPENDICES

APPENDIX A

ALIQUOT AND SAMPLE AVERAGE DATES

The following is a record of each aliquot tested by OSL techniques, the resulting luminescence signal, and the calculated age. Aliquots that have an error term over 10% are indicated with double asterisks (**) in the note column. Aliquots marked "rejected" were not included in the final generated date because they had error terms over 10% and they fell outside the two sigma range on the radial plot.

Sample Number	Paleodose (Gy)	Gy error		Year (AD)	Error	Notes
241_1	21.51	0.99		441	170.44	** rejected
241_2	9.32	1.28		1329	114.75	**
241_3	10.28	0.50		1259	82.30	
241 Average				1294	98.53	
250_1	9.17	1.05		1029	122.68	
250_2	9.53	0.90		991	109.18	
250 Average				1010	115.93	
251_1	13.33	0.87		1117	100.52	
251_2	13.51	1.00		1142	110.39	
251_3	13.22	0.65		1178	85.56	
251 Average				1146	98.82	
252_1	9.66	1.94		1491	107.17	**
252_2	9.23	1.00		1514	59.37	**
252_3	10.37	0.33		1453	33.79	
252 Average				1486	66.78	
253_1	8.59	1.10		1237	114.17	**
253_2	7.2	1.62		1362	153.05	**
253 Average				1300	133.61	
254_1	8.95	0.29		1438	22.76	
254_2	90.61	9.65		920	155.03	** rejected
254 Average				1438	22.76	
255_1	10.01	0.97		1387	98.42	
255_2	8.91	1.03		1456	94.25	**
255_3	9.63	0.89		1411	93.07	
255 Average				1418	95.25	
256_1	8.64	1.28		1377	102.58	**
256_2	9.39	0.84		1323	76.71	
256_3	10.17	0.72		1266	72.51	
256 Average				1322	83.93	
257_1	18.64	1.71		1150	114.97	
257_2	18.66	1.71		1149	115.03	
257 Average				1150	115.00	

Sample Number	Paleodose (Gy)	Gy error		Year (AD)	Error	Notes
378_1	14.96	0.44		1334	34.13	
378_2	14.52	0.58		1353	37.55	
378_3	14.79	0.58		1341	37.92	
378_4	16.11	0.46		1282	36.39	
378_5	15.00	0.29		1332	30.76	
378 Average				1328	35.35	
379_1	13.53	0.18		1430	20.83	
379_2	17.76	0.50		1249	33.20	
379_3	15.62	0.42		1340	28.67	
379_4	15.35	0.39		1352	27.58	
379_5	15.27	0.35		1355	26.48	
379 Average				1345	27.35	
380_1	15.01	0.28		1438	22.03	
380_2	15.79	0.31		1408	23.47	
380_3	14.19	0.42		1469	24.24	
380_4	15.55	0.72		1417	33.89	
380_5	18.82	0.35		1293	27.60	
380 Average				1405	26.25	
381_1	13.00	0.21		1414	29.37	
381_2	12.55	0.22		1425	28.62	
381_3	13.36	0.46		1398	35.44	
381_4	13.49	0.42		1392	34.61	
381_5	13.47	0.42		1393	34.58	
381 Average				1404	32.52	
382_1	14.95	0.39		1367	30.70	
382_2	14.43	0.47		1389	32.00	
382_3	14.86	0.34		1371	29.45	
382_4	15.11	0.32		1360	29.41	
382_5	14.22	0.36		1398	26.90	
382 Average				1377	29.69	
383_1	12.82	0.33		1440	25.19	
383_2	12.80	0.37		1441	26.21	
383_3	13.47	0.51		1411	31.24	
383_4	14.75	1.45		1354	68.53	
383_5	14.82	0.41		1351	29.88	
383 Average				1399	36.21	
384_1	3.90	0.28		1849	12.75	
384_2	4.30	0.39		1833	17.10	
384_3	5.88	0.50		1768	22.12	
384_4	4.71	0.27		1816	12.95	
384_5	7.81	0.91		1689	38.85	** rejected
384 Average				1817	16.23	

Sample Number	Paleodose (Gy)	Gy error		Year (AD)	Error	Notes
385_1	3.66	0.33		1859	14.45	
385_2	3.62	0.56		1861	23.46	**
385_3	4.63	0.44		1819	19.15	
385_4	3.76	0.23		1855	10.81	
385_5	3.38	0.29		1870	12.79	
385 Average				1853	16.13	
386_1	3.39	0.29		1873	12.41	
386_2	3.61	0.47		1865	19.34	**
386_3	3.84	0.45		1855	18.65	**
386_4	4.57	0.33		1826	14.48	
386 Average				1855	16.22	
387_1	6.89	0.49		1773	18.43	
387_2	7.23	0.36		1761	14.71	
387_3	7.23	0.38		1761	15.29	
387_4	6.82	0.56		1775	20.60	
387_5	6.90	0.51		1773	19.06	
387 Average				1769	17.62	
388_1	7.75	0.24		1656	17.27	
388_2	4.89	0.48		1786	24.43	** rejected
388_3	7.45	0.46		1669	24.58	
388_4	8.27	0.22		1632	17.44	
388_5	7.31	0.47		1676	24.84	
388 Average				1658	21.03	
389_1	18.56	0.70		1293	38.01	
389_2	19.72	0.53		1249	35.03	
389_3	18.00	0.71		1315	25.97	
389 Average				1286	33.00	
390_1	15.49	0.70		1365	38.27	
390_2	18.09	0.43		1257	34.11	
390_3	17.43	0.43		1285	33.21	
390_4	16.83	0.60		1310	36.77	
390_5	17.19	0.41		1295	32.44	
390_6	16.99	0.70		1303	39.88	
390 Average				1303	35.78	
391_1	18.21	0.35		1223	33.52	
391_2	18.51	0.43		1236	34.68	
391_3	17.29	0.47		1287	33.96	
391_4	18.06	0.41		1255	33.21	
391_5	18.72	0.39		1227	34.14	
391 Average				1246	33.90	

Sample Number	Paleodose (Gy)	Gy error		Year (AD)	Error	Notes
392_1	18.05	0.35		1208	35.33	
392_2	17.58	0.45		1229	36.80	
392_3	17.77	0.54		1220	39.37	
392_4	17.21	0.36		1245	34.22	
392_5	15.06	0.83		1340	45.35	
392 Average				1248	38.21	
393_1	14.07	0.63		1318	42.82	
393_2	14.95	0.55		1074	44.82	
393_3	15.63	0.44		1241	39.35	
393_4	15.24	0.41		1260	37.87	
393_5	14.19	0.67		1312	38.35	
393 Average				1241	40.64	
394_1	17.94	0.27		1283	29.18	
394_2	19.03	0.41		1239	33.14	
394_3	19.43	0.40		1223	33.47	
394_4	20.26	0.91		1189	47.83	
394_5	19.41	0.49		1224	35.34	
394 Average				1232	35.79	
395_1	17.40	0.43		1364	24.29	
395_2	17.46	0.32		1362	21.89	
395_3	18.27	0.43		1332	24.99	
395_4	16.92	0.31		1382	21.21	
395_5	17.75	0.64		1351	30.20	
395 Average				1358	24.52	
397_1	8.24	0.39		1682	19.51	
397_2	11.29	0.47		1561	24.77	** rejected
397_3	10.04	0.35		1611	20.08	** rejected
397_4	7.89	0.31		1696	16.77	
397_5	7.97	0.22		1693	14.46	
397_6	7.89	0.29		1696	16.19	
397 Average				1692	16.73	
398_1	4.23	0.41		1832	18.26	
398_2	3.63	0.35		1857	15.59	
398_3	3.52	0.31		1862	13.98	
398_4	4.29	0.27		1830	13.01	
398_5	4.25	0.24		1831	11.91	
398 Average				1842	14.55	
399_1	15.59	0.44		1361	30.68	
399_2	15.46	0.31		1366	27.62	
399_3	15.08	0.31		1382	27.09	
399_4	14.86	0.36		1391	27.85	
399_5	15.72	0.64		1355	36.39	
399 Average				1371	29.93	

Sample Number	Paleodose (Gy)	Gy error		Year (AD)	Error	Notes
400_1	7.04	1.10		1749	41.48	**
400_2	6.44	0.70		1771	27.04	**
400_3	5.59	0.61		1803	23.56	**
400_4	5.99	0.52		1788	20.60	
400_5	5.94	0.49		1790	19.55	
400 Average				1780	26.45	
401_1	12.13	0.67		1558	28.94	
401_2	11.80	28.00		1570	17.71	
401_3	12.79	0.60		1533	27.18	
401_4	12.21	0.36		1555	19.97	
401_5	11.41	0.32		1584	18.26	
401 Average				1560	22.41	
402_1	15.99	1.06		1390	46.38	
402_2	18.54	1.03		1291	47.10	
402_3	15.50	0.62		1408	31.86	
402_4	17.24	0.54		1341	31.31	
402_5	13.67	0.38		1479	23.62	**rejected
402 Average				1358	39.16	
403_1	7.55	0.62		1594	39.12	
403_2	8.05	0.74		1567	45.52	
403_3	7.05	0.78		1622	46.43	** rejected
403_4	7.98	0.63		1571	40.15	
403_5	9.17	0.73		1506	46.42	
403 Average				1560	42.80	
404_1	4.43	0.43		1831	18.34	
404_2	4.14	0.68		1843	27.85	**
404_3	4.71	0.62		1820	25.71	**
404_4	5.08	0.33		1800	15.08	
404_5	4.39	0.31		1833	13.91	
404 Average				1825	20.18	
405_1	8.29	1.17		1646	53.17	**
405_2	6.34	0.84		1727	38.41	**
405_3	7.33	0.55		1688	27.24	
405_4	6.57	0.37		1721	19.82	
405_5	6.28	0.26		1734	15.78	
405 Average				1703	30.88	
406_1	4.09	0.48		1850	19.42	**
406_2	3.44	0.54		1875	21.44	**
406_3	3.38	0.36		1877	14.69	**
406_4	3.95	0.22		1855	10.07	
406 Average				1864	16.41	

Sample Number	Paleodose (Gy)	Gy error		Year (AD)	Error	Notes
407_1	6.27	0.24		1769	12.21	
407_2	5.38	0.70		1803	27.67	**
407_3	5.61	0.45		1794	18.66	
407_4	6.31	0.83		1767	32.78	**
407_5	4.38	0.39		1841	15.95	
407 Average				1795	21.45	
408_1	10.88	1.07		1587	43.88	
408_2	9.45	0.71		1643	30.22	
408_3	11.72	0.87		1555	37.11	
408_4	7.95	0.38		1701	18.11	** reject
408_5	10.54	0.64		1600	28.46	
408 Average				1596	34.92	
409_1	15.60	0.42		1376	30.17	
409_2	15.71	0.82		1371	41.34	
409_3	16.74	0.41		1329	31.48	
409_4	16.54	0.38		1338	30.57	
409_5	16.31	0.37		1347	30.00	
409 Average				1352	32.71	

APPENDIX B

LABORATORY PROTOCOLS

Institute for Integrated Research on Materials, Environment and Society (IIRMES)

Luminescence Laboratory Protocol (Version 2)

This manual for laboratory procedures refers to the use of the Risø TL/OSL-DA-15 combined TL/OSL reader housed in the CSULB IIRMES laboratory. The protocol is derived from the work of Daniel Bush and James Feathers of the University of Washington Luminescence Lab. Care has been taken to insure that protocol conforms to federal, state and University regulation and policy with respect to laboratory operation. Users of this protocol are asked to bring any errors, omissions, and/or amendments to the attention of C.P. Lipo, Department of Anthropology, California State University, Long Beach (clipo@csulb.edu).

1. Project Information
    1. Each project should fill out a Project Information for Luminescence Analysis form. This form records the basic summary information for all samples submitted by an individual or any individual project.
    2. Project Code: Each Project should be assigned a three-letter code to identify it. For example: LMV.
    3. Project Number: For every project there should be a sequential number for unique sets of samples that are submitted. Many projects may only have 1 project number and samples may accumulate under that single number. However, in cases where a single project produces distinctly different sets of samples a separate number is warranted.
    4. The form should record:
        i. Start Date (use DDMMYYYY format, e.g., 05Jun2005). This is when the samples were first submitted.
        ii. End Date (use DDMMYYYY format, e.g., 05Jun2005) This should record the point at which the project is considered "finished" (if ever).
        iii. IIRMES Project number (e.g., 0001). The IIRMES Project Number is a sequential number given to overall projects that are worked on in the lab. This number can be obtained by entering information in the IIRMES project log.
        iv. Technician Initials (e.g., CPL, JVD, etc.). Be certain to enter your initials into the CSULB Luminescence Laboratory Logbook
        v. Project Owner – Last name (e.g., Lipo)
        vi. Project Owner – First name (e.g., Carl).
        vii. Contact Information: Information as to how one can get hold of the sample submitter – phone, email, address.

viii. Project Locations: Information as to site names, region, locations of samples. Latitude and Longitude is particularly important.
ix. Number of Samples: Numbers of samples submitted as part of the project. This can be incremented over time.
x. Sample Types: Choose all of the sample types that apply.
xi. Context: Choose all of the sample contexts that apply.
xii. LB Sample Numbers: If there is some list of numbers used add them here. Use the comments section to add more numbers if needed. (e.g., LB001-25, LB0050-100, etc).
xiii. Analysts: Names of all individuals involved in analysis.
xiv. Sample State: As parts of the project are completed, check off the state that has been completed.
xv. Comments. Any additional information. Be sure to note here any grant numbers/names that should be acknowledged as part of the project.

2. Sample Identification and Documentation
    1. Samples are individually logged in the LB Luminesence Log sheets. These numbers (LB numbers) are sequential for each sample processed. The LB number is the central tracking number and is unique.
    2. Prepare a sample storage box.
        i. With the top hinge to the left, record the following data on the short side of the sample storage box. The data you should record includes:
            1. IIRMES Project Number (e.g., 0001). The IIRMES Project Number is a sequential number given to overall projects that are worked on in the lab. This number can be obtained by entering information in the IIRMES project log.
            2. LB sample # (e.g., 1000). The LB sample number is a sequential number given to each sample that will be dated. It will usually consist of a sample and material (e.g., sediments) for dosimetry. The sequential number can be obtained by entering information in the LB Luminescence Logbook.
            3. Sample ID (e.g., RM-16 1). The Sample ID is the number given to the sample by the original researcher.
            4. Date (always use this format: DDMMMYYYY. 06JUL2004).
            5. Technician Initials (e.g., CPL, JVD, etc.). Be certain to enter your initials into the CSULB Luminescence Laboratory Logbook
    3. Prepare a plastic 25ml beaker. Label with LB # and put into box.

4. Record sample description information on the top of either the Ceramic Coarse Grain Luminescence Analysis or the Ceramic Fine Grain Luminescence Analysis worksheet.
    i. Project Code: This is the 3 digit project code from the Project Information for Luminescence Analysis form
    ii. Project #: This is the sequential number from the Project Information for Luminescence Analysis form
    iii. Tech Initials: enter your 3 initials. Be certain these are recorded with your full name in the CSULB Luminescence Laboratory Logbook (e.g., CPL, JVD).
    iv. Date: This is the current date (format: DDMMMYYYY [e.g., 04APR2005]).
    v. LB Sample # as obtained from the CSULB Luminescence Laboratory Log (e.g., 0001).
    vi. Sample Information: General information about sample. These set of fields are used to describe the sample and the location from which it is derived.
        1. Markings from Sample. Record any text that is written on the original sample container (i.e., site, location, date, sample #s, etc.)
    vii. Sherd Thickness: Thickness is only roughly estimated with digital calipers and round to the nearest integer in 0.1 mm.
    viii. Protocol Code: FNG = fine grain, CG = coarse Grain.
        1. Version indicates the version of the protocol used (e.g., 01).
    ix. Photos Taken: Check whether photos have been taken of the sample and fill in the Photos box the location of these photos.
5. Sample Initial Weight. Record the initial weight of the sample (i.e., sherd, sediment) in the Sample Initial Weight field.
    i. Note: Weigh to a precision of 0.01 grams. Use the top-loading balance.
6. Percent Water Absorption: The sherd's thickness and percent water absorption must be measured.
    i. Percent water absorption is measured as follows:
        1. Saturate the sherd in deionized water for 24 hours.
        2. Weigh the saturated sherd by first removing any surface water by gentling dabbing the surfaces with a wet paper towel and then immediately placing the sherd on the scale. Weigh sample to 0.01 grams. Record the measurement as soon as the scale stabilizes, since the weight will continually decrease as water evaporates.
        3. Enter the value on the Sample Preparation Worksheet in the Saturated Weight field. Weigh sample to 0.01 grams.

ii. Dry the sherd in the oven at not more than 50-55°C for 24 hours and then record the weight again. Weigh to a precision of 0.01 grams. It is important to take the saturated weight before the dried weight, because the soaking in water may dislodge some material.
    1. Enter the value in the Sample Dry Weight field.
iii. Calculate percent water absorption by the following formula:
    1. W = [(S-D) /D] x 100
    2. where W = percent water absorption, S = saturated weight, and D = dried weight.
    3. Enter the values in the Percent Water Absorb field on the Sample Preparation Worksheet.

3. Radiation Sample Preparation
    1. When present, record and prepare associated radiation samples. Note that several samples may be present for each sherd. Consequently, the Sample Preparation Worksheet provides three entries to record information for the radiation samples.
    2. Numbers: The radiation materials should be given sequential numbers: r1, r2, r3 that are appended to the sample number (LB-1). Thus, the radiation materials should be labeled as LB-001-r1, LB-002-r2, LB-003-r3.
        i. Radiation Sample Distance from Sample. Record in centimeters the distance the radiation material was taken from the sample. Use the nearest centimeter (if known).
        ii. Radiation Sample Depth from Surface. Record in centimeters the distance the radiation sample was taken from the surface. Round to the nearest centimeter.
        iii. Calculate the necessary amount of sample required for total radioactivity measurements. This is usually no more than 1-5 grams.
        iv. Remove the necessary amount of sample, place and weigh in a tared container and record the weight in the Sub Sample Weight field (use grams). Weigh sample to 0.01 grams. This is the sub-sample.
        v. Note the amount removed and date on the original bulk container and sub sample container.
            1. Note the destination radioactivity analyses on the sub sample container (e.g., LA-ICP-MS/ ICP-MS with digestion/ Gamma Spectrometry, alpha counting, etc).
        vi. Place the sub-sample to be analyzed in the “Radiation Sample Processing Drawer.”

vii. Weigh and archive remaining sample as “Voucher”. Weigh sample to 0.01 grams. Record this information in the Voucher Weight field on the Sample Preparation Worksheet.
viii. Return the remaining material to the sample box.

4. Sample Preparation
    1. Ceramics
        i. The purpose of this technique is to disaggregate the sherd into its composite grains. Once disaggregated, two different protocols can be used to collect different grain size fractions:
            1. Coarse Grain Analysis: Typically, this will involve collecting quartz grains of sizes around 90-125 microns. Quartz has little internal sources of radiation, so the interiors of grains of this size will not be subject to alpha radiation which need not be considered in the calculations. The grains are small enough to limit beta attenuation. This technique often requires a fairly large sample, depending on the amount of quartz of proper size.
            2. Fine Grain Analysis: This consists of collecting all grains between 1 and 8 microns. Samples are mixed mineral so they included quartz and feldspars. This results in some additional analyses to determine whether fading is an issue (for feldspars). We also have to consider the alpha radiation contribution to the equivalent dose.
            3. Both analyses involve the same set of initial processing – at least through disaggregation.
        ii. Note: All sample preparation from this point on should take place in filtered light. The LB Luminescence Laboratory makes use of Philips 18W Compact Fluorescent Lamps that are installed into darkroom light boxes hanging from the wall. These bulbs were purchased at the Home Depot. These are covered with three layers of Lee 106 Filters. These filters are available for about $6/filter (1 provides 4 layers for the light boxes).
        iii. For the spectrum for this lighting combination see Huntley and Baril 2002.
        iv. For reading scales and looking in dark cabinets, we have available several small LED flashlights (the Photon Micro-Light orange LED). These can provide illumination for brief periods of time. The Photo Freedom Micro are $19.95 each and available. Several gooseneck holders are available for holding the light when working on scales, etc.

v. You should have already calculated the Percent Water Absorption for the ceramic. If not, do this procedure. Make sure you have recorded the sample dry weight (this is part of the H_2O Absorption Procedure).

vi. Before you break off a portion, weigh the sample to 0.01 grams. Record this information in the Initial Sample Weight.

vii. You should break off a portion to be saved for confirmation purposes or if additional material is need for analyses.
    1. Break off a portion of the sherd.
    2. Weigh and place in a bag labeled LB-____-v1 (where ___ is the LB Sample #). Weigh to 0.01 grams.
    3. Record the weight in the Sample Voucher Weight field of the Sample Preparation worksheet.
    4. Place the labeled voucher sample in the sample box.
    5. Record the weight of the remaining portion to be used for luminescence measurements in the Sample Remainder Weight field. Weigh to 0.01 grams (using the top loading balance).

viii. Remove the outer 2mm of the sherd.
    1. If the sherd is large enough and your hand is steady enough, use the diamond rock saw to remove the outer 2 mm from each surface and edge. Because of sherd curvature this may entail cutting the sherd into small fractions initially.
        1. You will want to place a sliced weighing boat under the saw to collect pieces for dosimetry.
    2. Alternatively, a Dremel drill with a diamond blade can be used. This should be clamped to the bench for stability. The diamond blade is fairly effective at removing the outer surfaces of the sherd. Most samples in this study were scoured using this method.
        1. Be sure to put paper underneath the diamond saw while grinding/collecting to collect material for the dosimetry analyses (alpha counting as well as ICP-MS).
    3. Also, save the outer portions/ground portions for dosimetry. You will need at least 1.0 g for this purpose (the more the better). It may be easier to break a section of the sherd off prior to processing to ensure that enough is available for dosimetry. This is particularly true in larger sherds.

1. Record the weight of this dosimetry sample in the Dosimetry Sample Weight field on the Sample Preparation Worksheet. Weigh to 0.01 grams.
2. Place the sample in a container and label. Use the label: LB-___-dl where ___ lists the LB Sample #.
3. Place the Dosimetry Sample in the "Radiation Sample Processing Drawer."

4. Weigh the remaining sample and record the weight on the Weight after Surface Removed field of the Sample Preparation Worksheet. Weigh to 0.01 grams.

ix. The next set of steps involves crushing the sample to disaggregate the grains from the sherds. The goal is to get as many independent, clean grains as possible.

1. Dry the inner, portions (in oven at 50°C)- the portion of the sherd from which the exterior was removed.
2. Clean two stainless steel plates for vice with ethanol and chemwipe. Make sure surface is clean
3. Place sherd on stainless steel plate. Put second plate on top of sherd and lightly tap to break sherd in to small pieces. You will probably need to move the plates back and forth to spread the grains out.
4. Once the sherd has broken into pieces, place the two plates in the wall vice. Be careful not to drop sample from the plates.
5. Tighten vice as tightly as possible. Release vice and slide plates back and forth to spread grains out.
6. Repeat at least 5 times. Plates should close to only a tiny amount when sherd is sufficiently crushed.
    1. Remember, the purpose being to disaggregate the grains but not to crush them.
7. Clean and prepare the agate mortar. You may need to rinse in sonicator for 10 minutes to clean out material. Dry and wipe down with ethanol.
8. Place crushed sherd into agate mortar. Do NOT use a ball – just the sherd. Use the cork seals at either end of the mortar.
9. Place the agate mortar into the ball mill. Be careful not to drop the agate mortar or to let either end of the mortar to open and spill sample.
10. Run the ball mill for 10 minutes.
11. Once disaggregated – the procedure that follows will depend on the Coarse Grain Analysis or the Fine Grain Analysis.

5. Fine Grain Analysis
    1. The purpose of this technique is to separate out small grains between 1 and 8 μm.
    2. The procedures before grinding sample are same as Coarse Grain Technique (see a. Coarse Grain Technique ii ~ viii in protocol).
    3. Take the sample from the agate mortar (see the Sample Preparation instructions) and pour into a 63 micron screen that has a bottom pan and a cover (one of the small screens).
    4. Shake the screen for at least 5 minutes, tapping onto the counter top repeatedly.
    5. Remove the bottom pan and pour onto tared weighing paper. Weigh sample to 0.01 g using top loading balance. Record weight in the Fine Grain Sample Weight field.
    6. Pour sample into labeled 25ml plastic beaker.
    7. Pour the remaining material onto tared weighing paper. Weigh remaining sample (to 0.01 g using top loading balance) and record on the Coarse Grain Sample Weight field.
    8. Pour coarse sample in glass vial. Label with LB number and >63 micron samples. Put in storage box – this can be used for coarse grain analysis if desired.
    9. Disolve organics and CaCO3 from fine grained sample.
        i. Place beaker with sample under fume hood.
        ii. Add enough HCL (dilute – 18%) to cover sample
        iii. Wait until no reaction is seen – about 15 minutes. Add additional HCl if necessary
        iv. Add H202 and wait about 15 minutes.
    10. Rinse HCL out from samples completely.
        i. Transfer sample with diluted HCL into two or three centrifuge tubes. Wash all samples out from beaker with deionized H_2O.
        ii. Run centrifuge about 2 minutes until all upper liquid part looks clear.
        iii. Carefully discard clear liquid part and add deionized H_2O up to 1.5 cm below the top of the tube. Run centrifuge about 2 minutes again.
        iv. Repeat this with deionized H_2O twice more and then do this with acetone once.
    11. Grain size separation (smaller than 8 μm).
        i. Transfer samples with acetone into at least two 50 ml gradual cylinder. Wash all samples out from centrifuge tube with acetone. Add more acetone and bring up to exactly 30 ml line (6 inches high).

ii. Stir samples with glass stick and place cylinder in sonicator for 30 seconds to 1 minute until all particle mixed with acetone.
iii. Pull cylinder out from sonicator and place it on the table in fume hood and wait for exactly 2 minutes using timer.
iv. Immediately after 2 minutes, pour upper liquid part out from cylinder into another cylinder quickly and quietly. This portion of samples is smaller than 8μm, which require the further grain separation for the analysis.
v. Transfer the bottom part into beaker and dry it in oven at 50°C. Keep it as archive sample. In case, not many fine grains extracted, the archive samples may need to be processed again.

12. Grain size separation (larger than 1μm).
    i. Add more acetone into samples liquid (smaller than 8μm) and bring up to exactly 30 ml line (6 inches high).
    ii. Stir samples with glass stick and place cylinder in sonicator for 30 seconds to 1 minute until all particle mixed with acetone.
    iii. Pull cylinder out from sonicator and place it on the table in fume hood and wait for exactly 20 minutes using timer.
    iv. Immediately after 20 minutes, pour upper liquid part out from cylinder into beaker quickly but quietly. This upper liquid is discarded (less than 1μm).
    v. Keep the bottom particles for fine grain analysis (between 1 and 8 μm). Transfer these samples into transparent large glass flask or tube and dilute them with acetone. Add acetone until some stuff like figure on the other side of glass container can be seen through (but not so clear).
    vi. Prepare about 12 small flat-bottomed test tubes.
        1. Clean with ethanol 48 and place them in the test tube holders.
        2. Place in test tube holder –label row with tape and LB number.
    vii. Prepare 12 stainless disks for samples.
        1. Using coarse grit sandpaper to file the burrs off stainless steel discs.
        2. Place the discs in acetone, ultrasonic clean and dry them in the oven.
        3. Place one disc in each small test tube, either side up. (If aluminum discs are used, sand one side with emery paper. Place discs in dilute aqua regia until bubbles form on the surface of the discs. Rinse twice in distilled water, cleaning in the ultra-sound both times.)
        4. Rinse in acetone and dry in oven.

5. Place in test tubes with roughened side down.
6. Place the discs in the holder and put in the 50 C oven for at least 1 hour.
7. Remove and allow to cool to room temperature.

viii. Use 2ml pipette.

ix. Shake the sample well and squirt out a couple of measures to remove water from the dispenser. To insure an even distribution of material on the 48 discs, shake the container vigorously every 4-6 discs. Continue to shake and then place bottle with dispenser in ultrasonic cleaner. To insure an even distribution of material on the discs, shake the container vigorously every 4-6 discs. While being continually stirred, pipette 2.00 ml of sample into each small test tube containing the discs. The level in each test tube will be slightly different because of slightly different volumes, but if the sample dispensed into the test tube is greatly different than the average, try to adjust accordingly.

x. Poke each disc once with Teflon rod to remove any air bubbles that may have formed at the bottom of the disc after dispensing. Ultrasonic clean each test tube -for 5-10 seconds to thoroughly bring sample into suspension. Place the test tubes in oven at about 50°C to settle overnight. These are now ready for TL/OSL measurements.

xi. l) Clean all glassware used with detergent and deionized water. Rinse about 4 times and leave to dry on the drying rack overnight. Wash the dispenser out and leave it attached to a bottle of water and have it saturated with water so it does not dry out.

xii. On the next day remove the samples from the oven. These are now ready for processing.

xiii. Clean the small test tubes by letting them soak in water and detergent overnight and then rinsing them four times with water.

6. TL/OSL Measurements Fine Grained Analyses
    1. Prepare clean open area to work. Make sure lights are dim.
    2. Remove test tube holder with disks from oven to be measured for OSL/TL
    3. Use aluminum Risoe sample wheel for disks (note there is another one for planchets with slightly wider holes).
        i. Remove one test tube at a time.
        ii. Gently remove the disk from the test tube. You will want to be very careful here so at to not dump the disk upside down onto the bench.
        iii. Use the bent tweezers to aid your manipulation of the disks.
        iv. Place the disk into the sample wheel. It should fit right into the indexed hole on the wheel. If not, reposition.

v. Be extremely careful with the wheel – do not disturb it or you will lose all of your samples.
vi. Record the LB number, wheel position and sequence file used in the RisoeLog.xls file – on the computer attached to the Risoe.
vii. We usually do 4-5 aliquots for every fine grained analysis.
viii. Once the wheel is filled (or as many samples as you want are position), carefully move the wheel into the Risoe. It should fit on the spindle.
ix. Press the close bottom on the Risoe controller and hold to have the Risoe close (the button must be held to close the reader).
x. Once closed, the samples are ready for measurement.
xi. Make certain the RisoeLog.xls is up to date.

4. Measurement.
   i. Run the Sequence Editor program.
   ii. Use CPL as the user name (or name one of your own).
   iii. We use a standard SAR sequence file (_____.seq). You will have to modify it for your particular samples.
   iv. To modify, you will have to change the position numbers (in the first column).
   v. You will also want to identify the samples by clicking on "configuration" and then "samples". This allows you to enter the LB number and disk number for every position on the wheel. This is handy for later analyses.
   vi. Save the sequence file with this algorithm:
      1. <Date>-<Grain Size= CG or FG>-<Luminescence = BOSL or IrOSL or TL (or any combo)>-<Range of dose (e.g., 10-30 Gy)>-<run number>.SEQ
      2. Example: 5Jun2005-FG-BOSL-IrOSL-30-30Gy-1.SEQ
      3. Record this information on the RiseoLog.xls
   vii. Note that for unknowns you will have to do a run on a single disk using a wide range of doses based on estimated amount of equivalent doses. This is necessary so you can adequate bracket the sample dose with ones that you add. Initially you might want to do just one disk from each sample you plan to runand use a range of 10 to 100 Grys with a dose every 20 Grys. Once you get a result, you can evaluate what the paleodose looks like and more carefully bracket your samples (e.g., just do 10 to 30 Gy). You should only have to do this for unknown samples.
   viii. Make certain that the configuration does NOT have "one at a time" set – this will add significant time to the measurements.
   ix. Double check your columns: do you have the right positions indicated for your measurement (e.g., 1-40, 1-5, etc.).

x. When finished, hit "Run". You will be asked where to save the results and what to name them. Use the default location (usually "Bin files") and the same name as the sequence except for the BIN extension: e.g., 5Jun2005-FG-BOSL-IrOSL-30-30Gy-1.BIN.

xi. It is estimated that it will take about an hour per aliquot. Maybe more.

5. Risoe Configuration: The standard Risø reader is equipped with a 7.5 mm Hoya U-340 detection filter, which has a peak transmission around 340 nm (FWHM = 80 nm)

Institute for Integrated Research on Materials, Environment and Society (IIRMES)

X-Ray Fluorescence Laboratory Protocol

This laboratory protocol refers the use of the Keymaster Technologies, Inc. Burker AXS TRACeR III-V Portable X-ray fluorescence elemental analyzer owned by the CSULB IIRMES Laboratory. It is derived from the Keymater Technologies, Inc. and Burker Analysis user's manual for the TRACeR III-V instrument.

1. Create pellet with internal standard for elemental analysis. Two pellets are made for each sherd, a dosimetry sample pellet and a radiation sample pellet.
    1. Pulverize sample using mortar and pestle.
        i. Wash mortar and pestle with tap water and rinse with DI water, then dry with kimwipe.
    2. Transfer ground samples into labeled glass vial.
        i. Pour ground sample onto folded weighing paper before transfer.
    3. Weigh Samples.
        i. First, weigh plastic vial, cap, and ball (for shaker mill later) and record as empty vial, ball, and cap weights (A).
            a. This needs to be done prior to weighing sample, since the loss of sample form transfer will be calculated later.
        ii. Weigh 300 ± 10mg of dried sample in the weighed plastic vial with sample name.
            a. Place plastic vial on balance and push re-zero button and then pour powdered sample into vial until it reaches 300mg.
            b. Record as original weight (B). Make sure to cover the lid of the balance.
            c. Use weigh paper to transfer.
    4. Add internal standard.
        i. Wear latex glove for protection.
        ii. Shake 40ppm Indium (In) internal standard solution well.
            a. Solution should have 2% nitric acid and the In internal standard mixed.
        iii. Pipette 1ml of this into 300mg powdered sample in the plastic vial with weighed sample.
            a. Make sure dial on pipette is at 1ml.
        iv. Place sample with standard in the oven at 70-75°C for four hours or until completely dry. Do not exceed 75°C during drying.
        v. Remove from oven and weigh vial with sample and standard on balance (G).
    5. Homogenize samples with internal standard.
        i. Crush dried sample roughly with wooden stick first before using shaker mill. Put a ball (already weighed and stored in the plastic bag labeled with the sample ID) in this vial.

ii. Set shaker mill for 30 minutes. Turn on the mill and place vials in shaker slots.

6. Remove homogenized sample with internal standard from shaker and transfer to new vial.
   i. Weigh the homogenized sample and record the transferred sample weight (D).
   ii. Use wooden sticks to scrape out as much sample as possible without etching the glass or plastic of the vial.
7. Add binder powder into transferred samples and bring up to 1 gram as total (E).
   i. Calculate dilution factor and record. Dilution factor: (D) / (E)
   ii. Weigh the old vial, cap, and ball and record as after use weight (F).
   iii. Calculate the loss from transferring. Loss from transfer: (F) – (A).
   iv. The real concentration of the internal standard in the powdered sample:

$$\frac{G-(F-A)}{G} \times 40\text{ppm}$$

8. Make a pressed pellet
   i. Mix sample with internal standards in the shaker mill for three minutes without adding balls.
   ii. Clean the 13mm die and dry with Kimwipe well.
   iii. Place one die in the press chamber with shinning surface up and then transfer sample with binder from vial into the chamber.
   iv. Cover with second die. Put small rod on top of die and place chamber on the press. Stabilize the chamber with screws on top of and on the side of the press.
   v. Pull the handle to add pressure until about 12 tons. Do not exceed 12 tons.
   vi. Release the screws and place the chamber upside down to extract pressed pellet.
   vii. Store pellet in plastic bag with sample name. Be sure to indicate Dosimetry (D-1) or Radiation (r-1) samples.

2. XRF Instrument Set-up
   1. Put desired filter in filter slot (behind brass screw).
      i. If doing low mass elements connect vacuum system. Low mass element filter is a titanium paper.
      ii. High mass element analysis does not require the vacuum. High mass element filter is marked “obs” and placed with the colored metal side facing the trigger mechanism.
      iii. Each pellet must be run twice, on both low and high, to gain all required elemental analyses.
   2. Connect laptop or computer to instrument with serial cable.
   3. Insert battery or connect instrument to AC power.
   4. Insert power key and turn instrument on.
      i. Yellow light should come on.

5. Cover IR safety sensor. Without this cover, the X-ray tube will not activate.
6. Place sample pellet in front of vacuum window.
    i. Depress trigger when analysis begins. Use a rubber band to hold down the trigger for the length of the analysis
7. Wait 1-2 minutes before bringing up software on computer.

3. Software Set-up
    1. Connect the instrument interface cable to the serial port on the computer.
    2. Double click on S1PXRF icon on desk top.
    3. Under DOWNLOAD check BAUD RATE to assure that it is 56700.
    4. Assure that the port number is also the one that you are using on currently on that computer. This can be found under the PORT option.
    5. Under File do PDZ PREVIEW and bring in a previously stored file so the spectrum is visible on the screen.
    6. Click on the red dot to turn it green if it is not already green, (usually checking the port number will turn it green).
    7. Under TUBE go to kti tube and then click on read and select the desired voltage and current.
        i. For low mass element analysis select the 15.00kv and 25.50 μa.
        ii. For high mass element analysis select the 40.00kv and 150.00μa.
    8. While this screen is up activate the instrument and assure that the instrument goes to the correct voltage and current.
        i. Trigger should be depressed at this point and the red light indicating active X-rays should come on. Follow all X-ray safety rules from this point on.
    9. Select the TIMED option.
        i. Choose Timed Assays and select 300 seconds (5 minutes) as the length of time for analysis.
        ii. Check PDZ, CSV, and Autosave. Be sure to rename the file with the sample number and indicate dosimetry (D-1) or radiation (r-1).

Institute for Integrated Research on Materials, Environment and Society (IIRMES)

Laser Ablated -Time of Flight –Inductively Coupled Plasma –Mass Spectrometer Laboratory Protocol

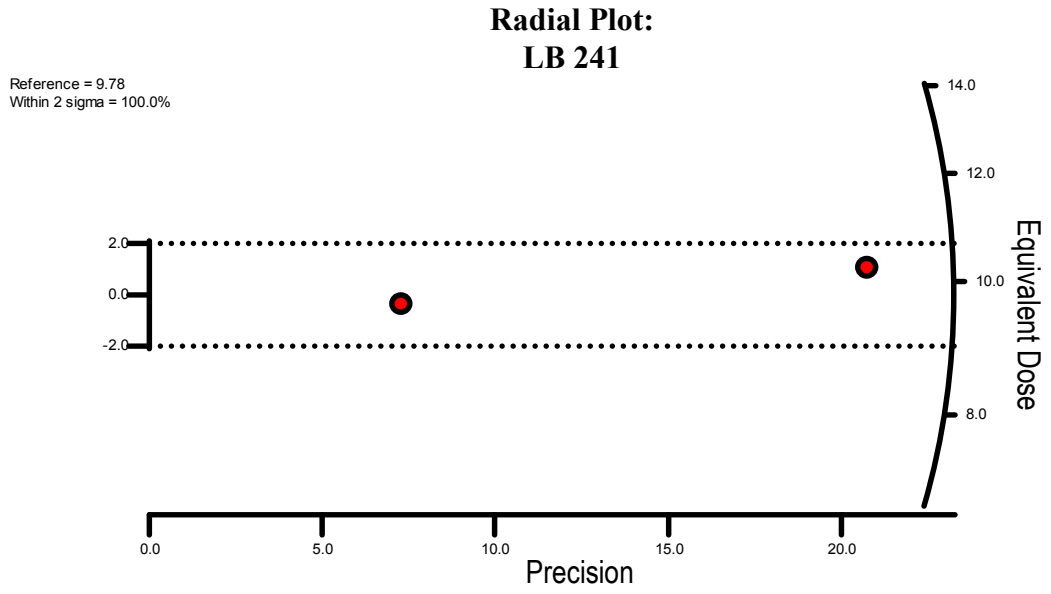
This protocol refers to the use of the GBC Optimass orthogonal TOF ICP-MS and New Wave 213 LUV Laser Ablation System housed in the CSULB IIRMES Laboratory facilities. It is derived from the laboratory exercises provided in the Anthropology 585 class developed by Dr. Hector Neff.

1. Follow same pellet protocol as in XRF instructions.
    1. Break off small piece of pellet and place onto slide. Be sure to keep track of sample numbers and locations on slide.
2. ICP-MS Instrument Start-up.
    1. Turn on chiller, helium gas, and argon gas supplies. Push "Ready" button on the TOF computer.
    2. Wait for instrument to startup and stabilize, then load the most recent instrument setting.
3. Open the "Acquire" and the "Tuning" windows and zoom to all mass ranges. Zoom in on each mass range to make sure there are none missing.
4. Engage laser ablation system.
    1. Step laser software up slowly until it reaches 60% power.
    2. Hit "purge" and wait for 30 seconds, then hit "online."
5. Go to time-scan window and set it up to monitor all isotopes.
    1. Draw a horizontal line on each sample in the laser to pre-ablate once.
    2. Set the laser to run the pattern three times, at 60% power with a 100-micron spot, at a speed of 50 microns per second and using a rep rate to 10Hz.
    3. Set the TOG for one second acquisitions and initiate continuous acquisition in the time-scan window.
    4. After a few seconds for pre-ablation, run the ablation pattern that you drew on the sample.
    5. Download the time-scan file and save.
6. Every 10 runs of sample, three glass standards are run as well as a blank. The standards used are SRM612, SRM614, and glass buttes obsidian.
7. Import the time-scan file into Excel.
    1. Subtract the blank value and calculate elemental concentration for each sample.

APPENDIX C

RADIAL PLOTS AND WEIGHTED HISTOGRAMS

Figure LB 241



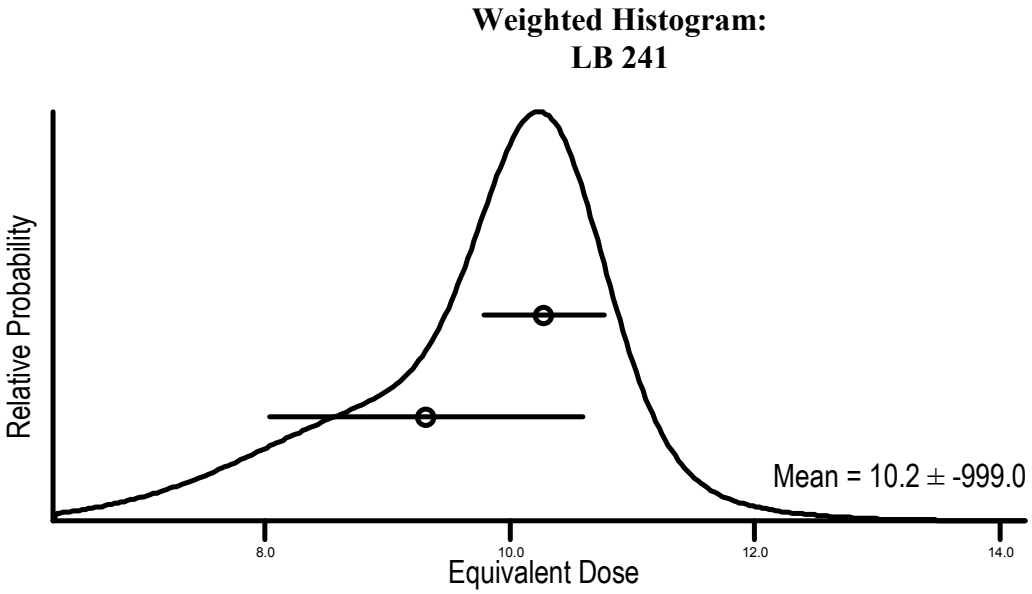
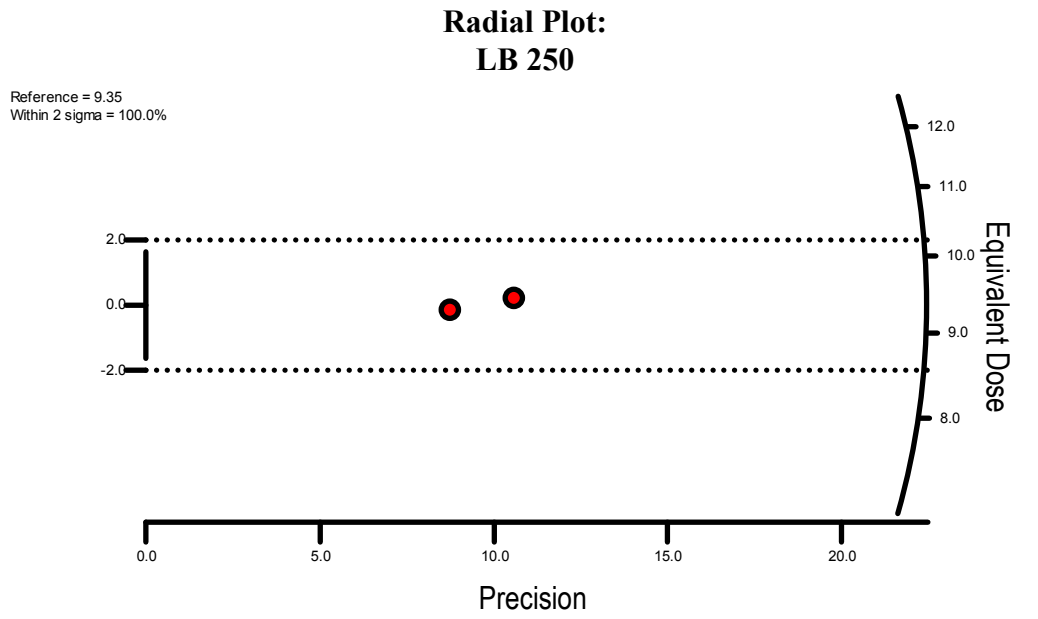


Figure LB 250



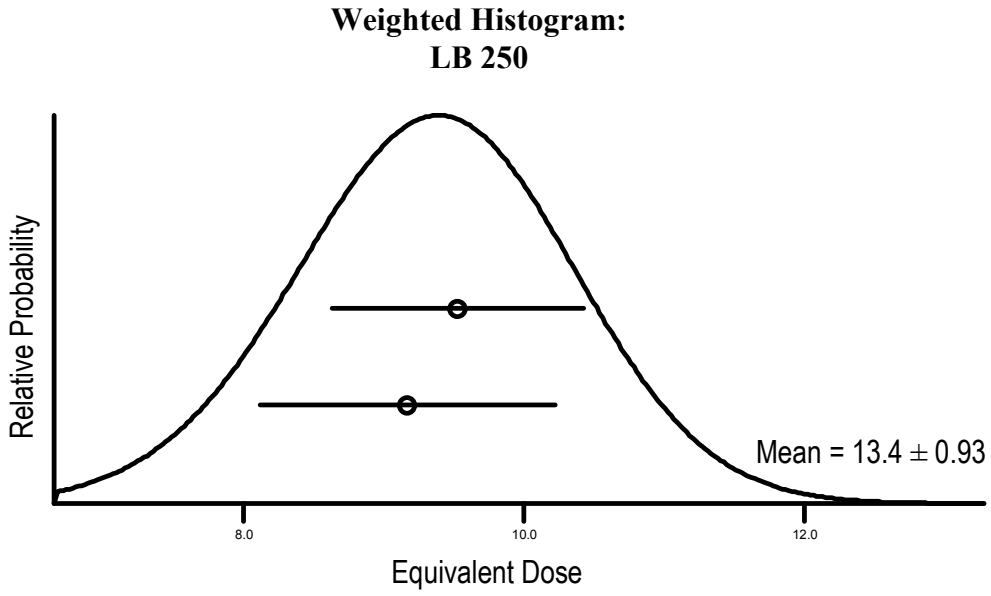
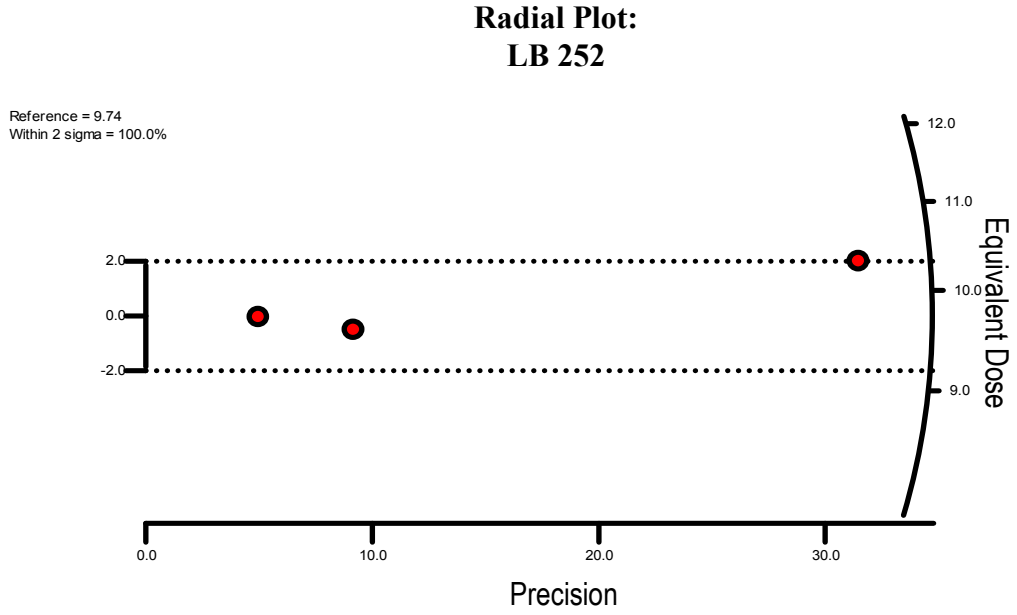


Figure LB 252



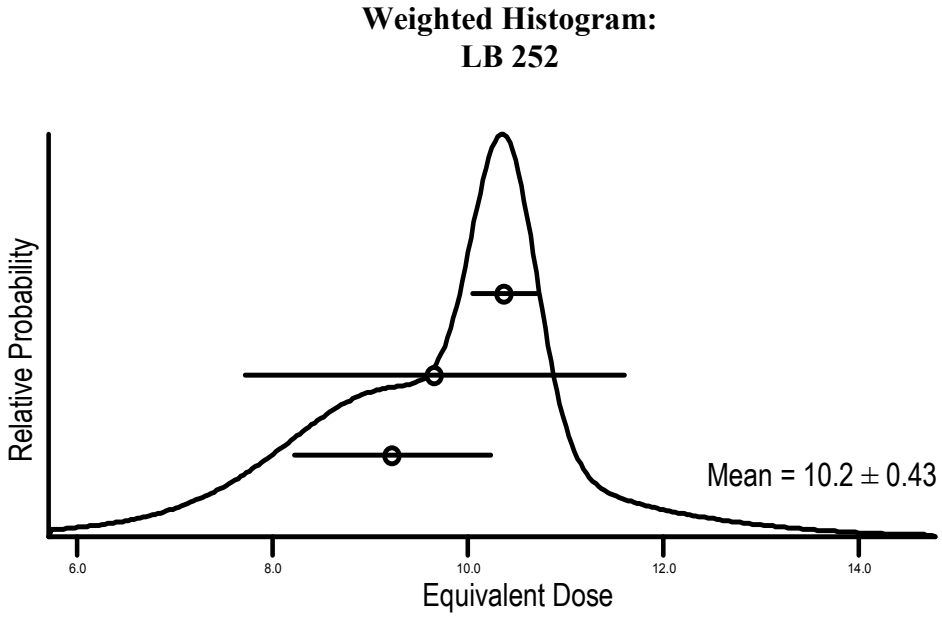
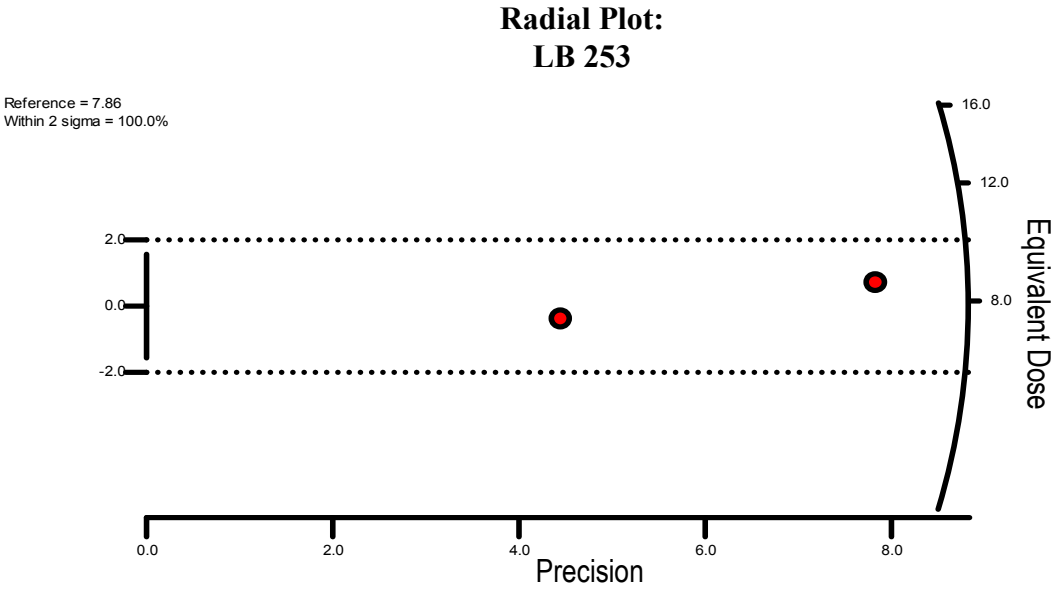


Figure LB 253



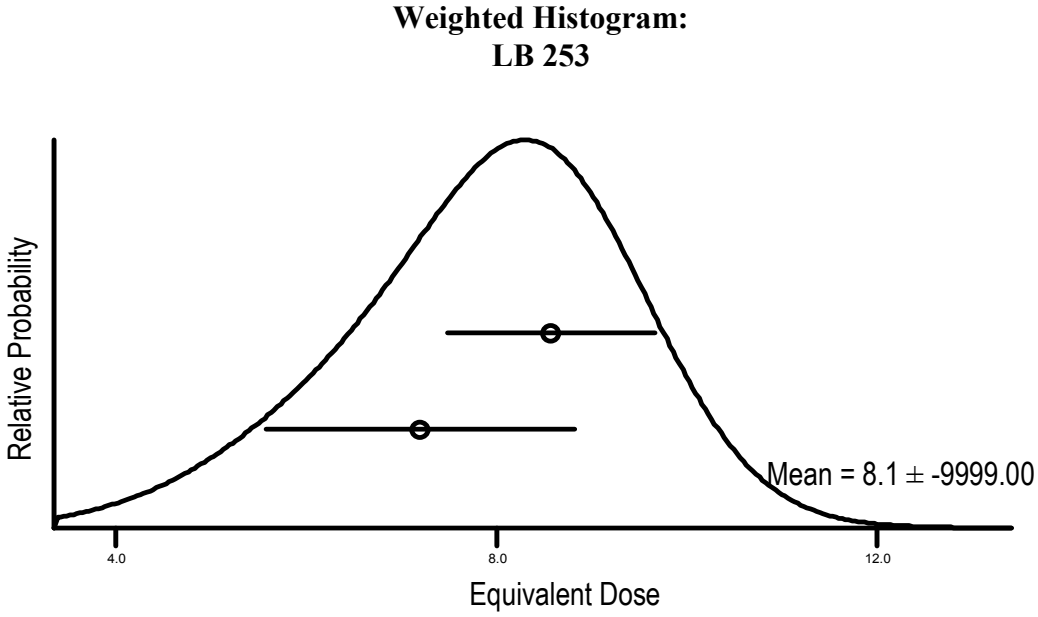
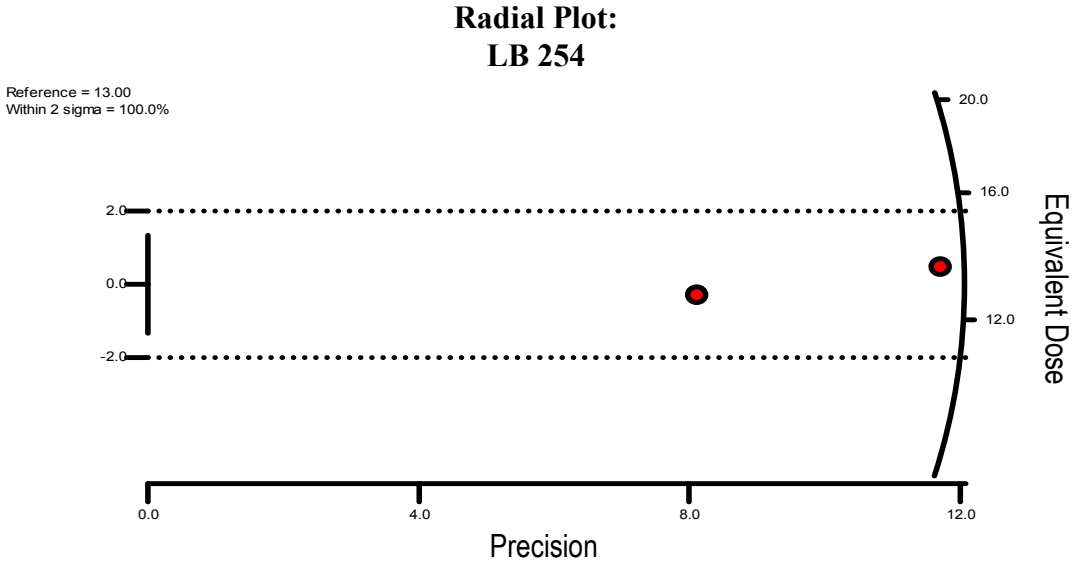


Figure LB 254



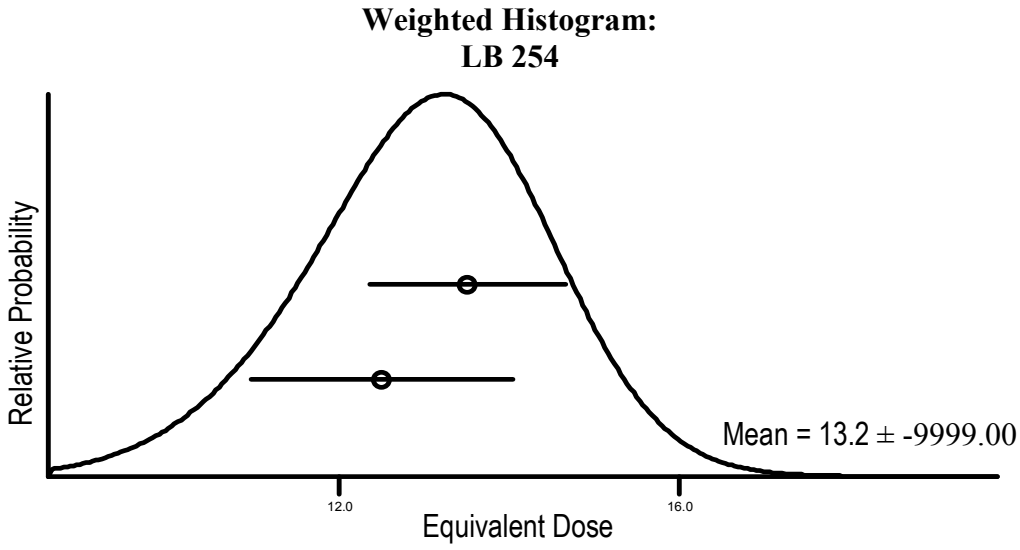
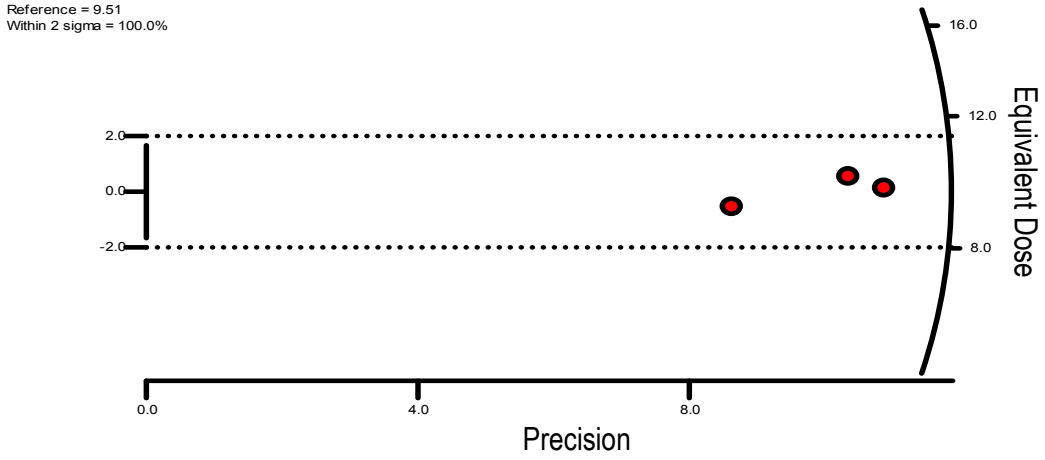


Figure LB 255

Radial Plot:
LB 255



Weighted Histogram:
LB 255

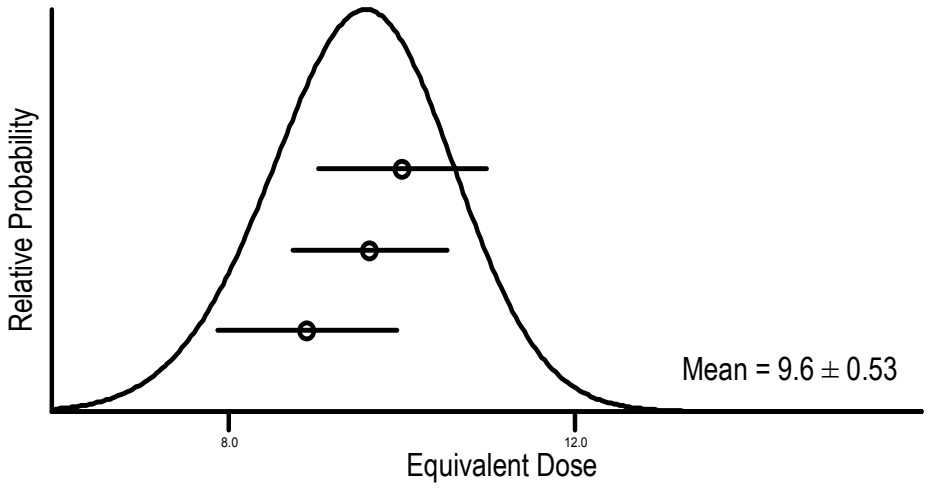
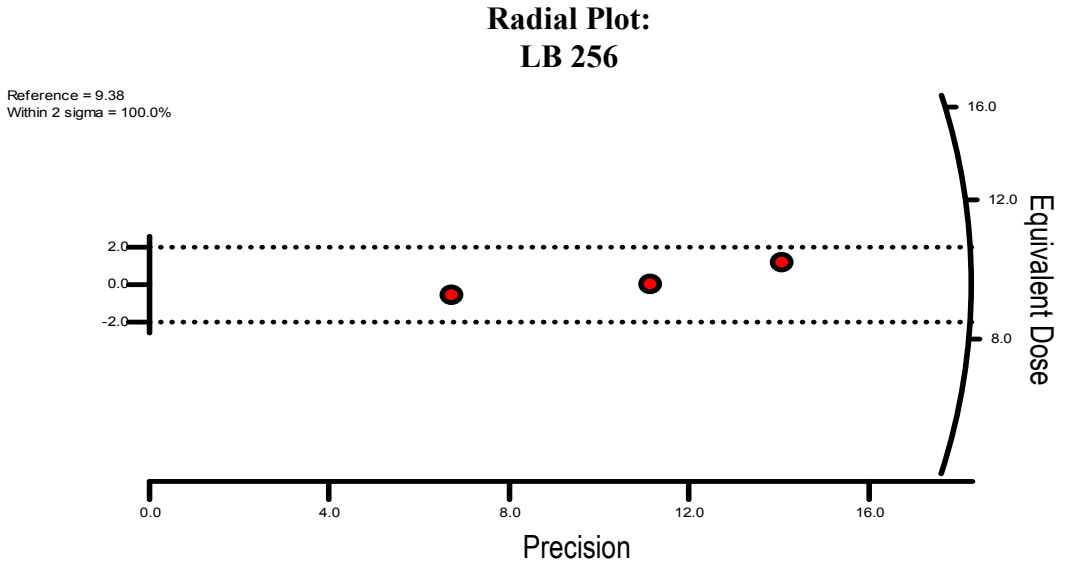


Figure LB 256



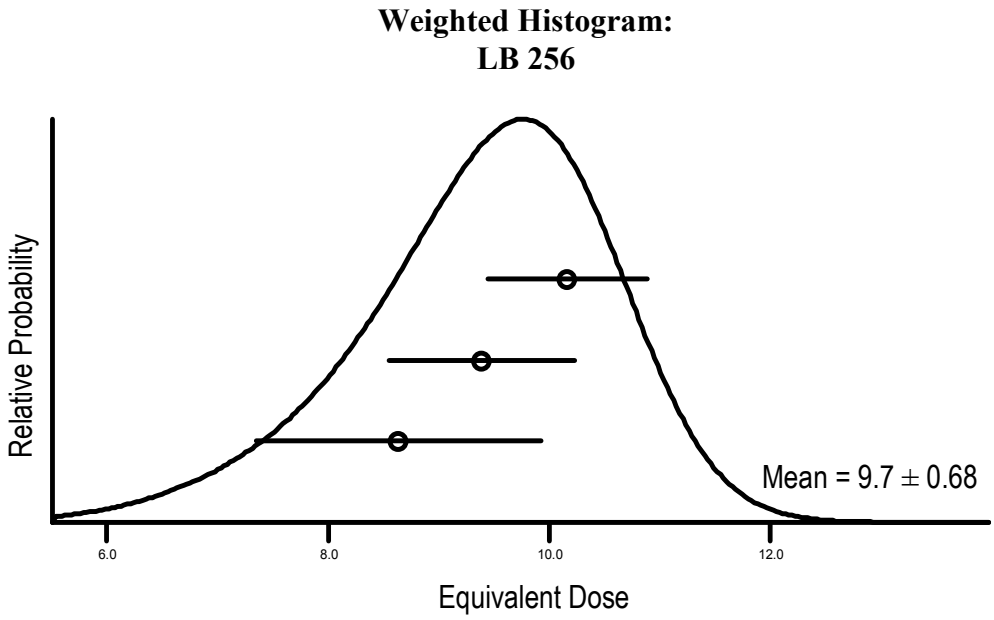
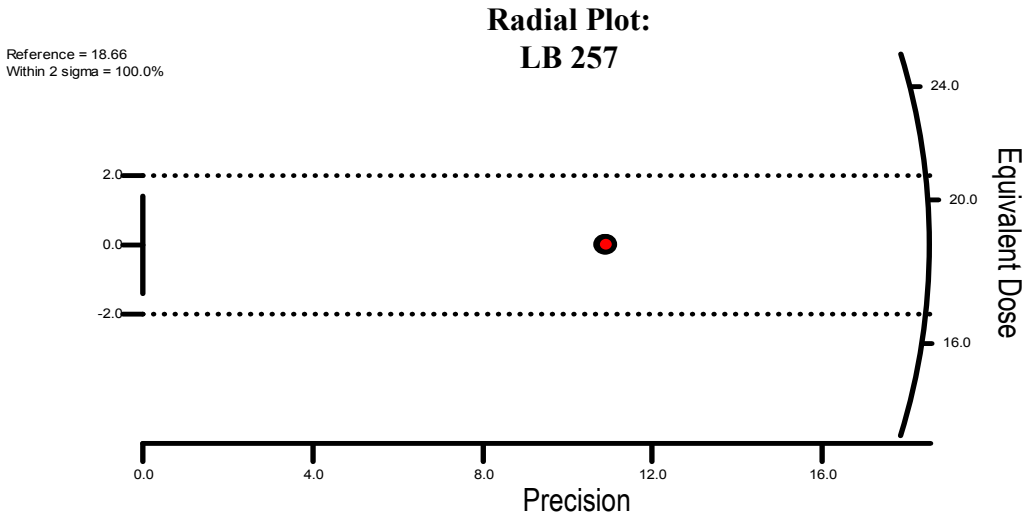


Figure LB 257



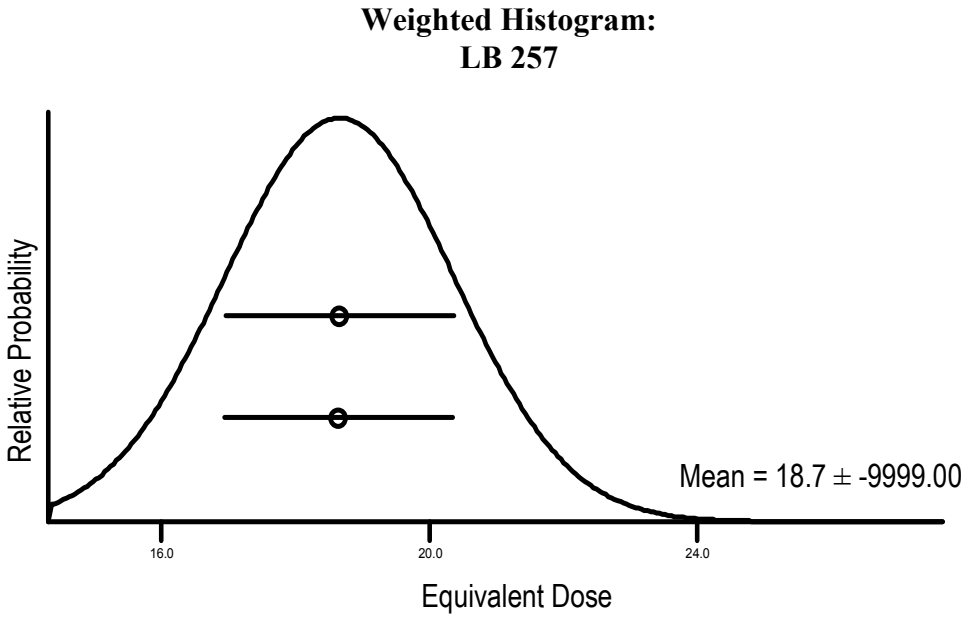
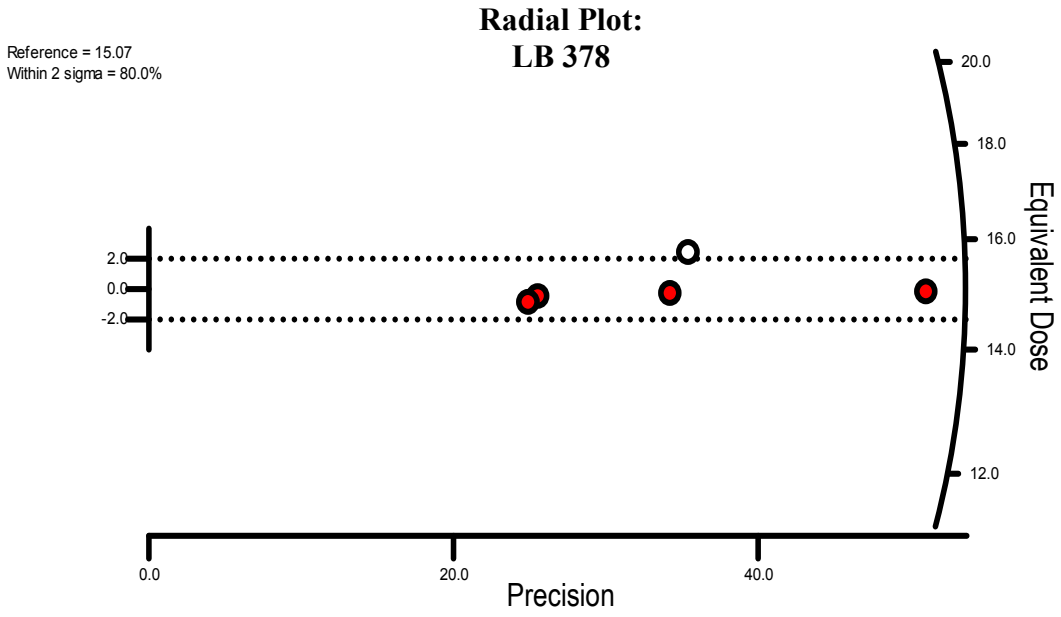


Figure: LB 378



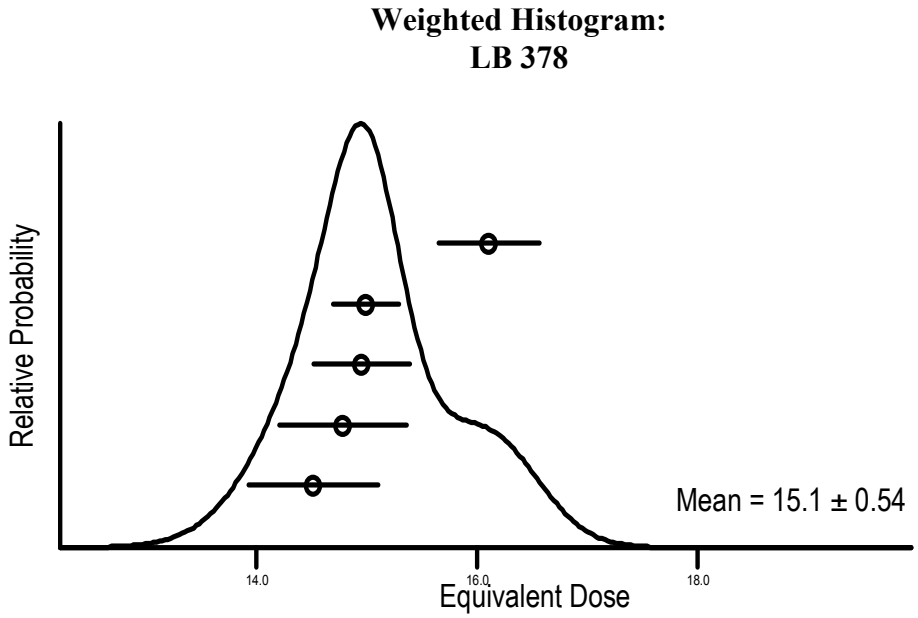
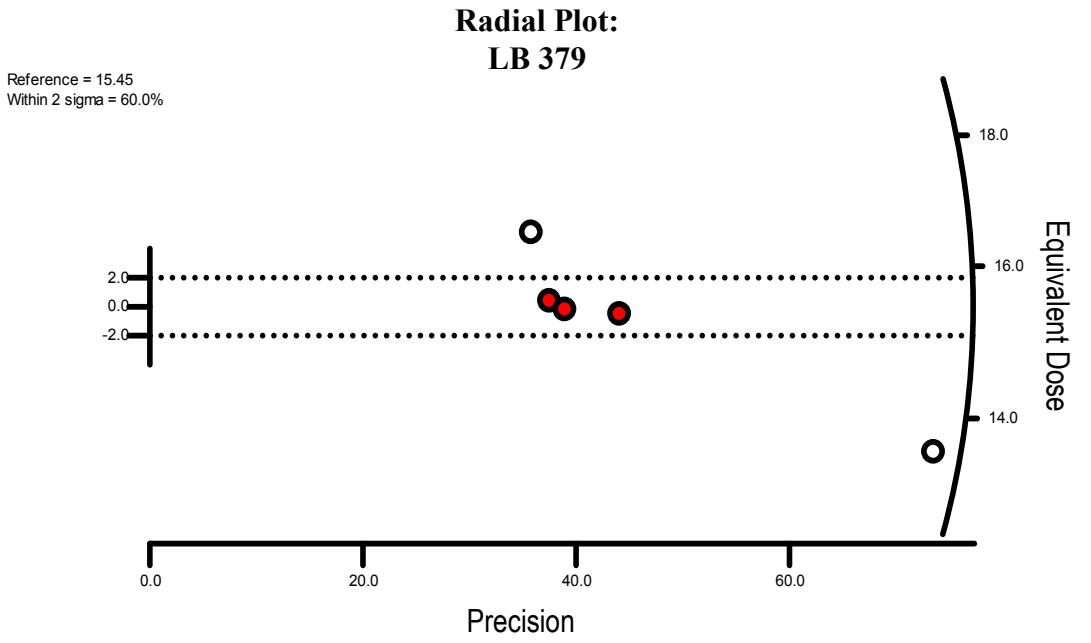


Figure: LB 379



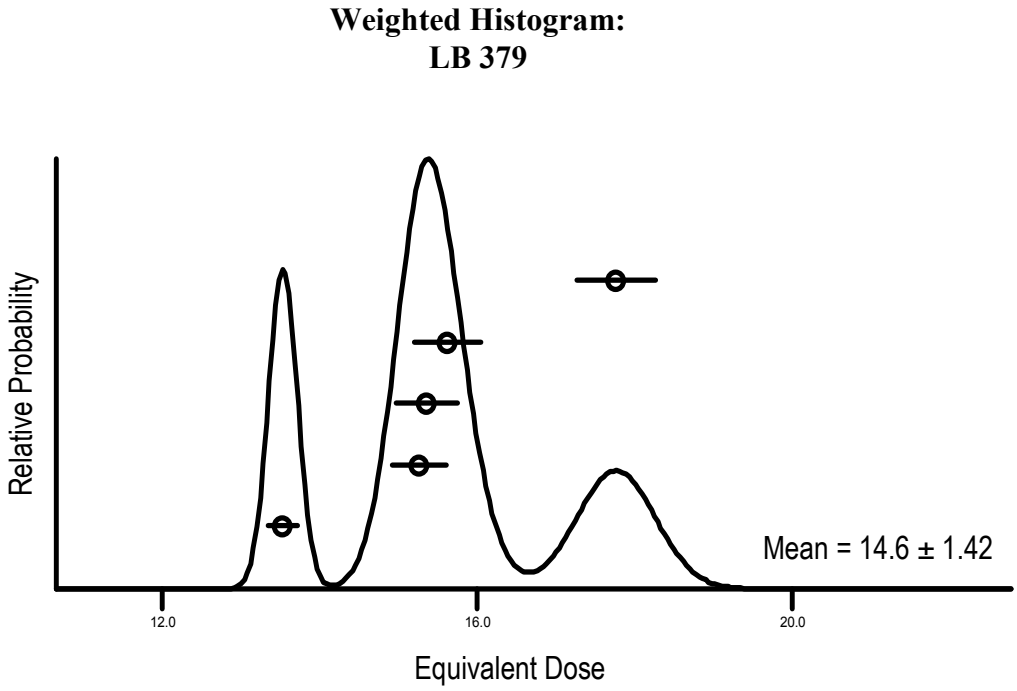
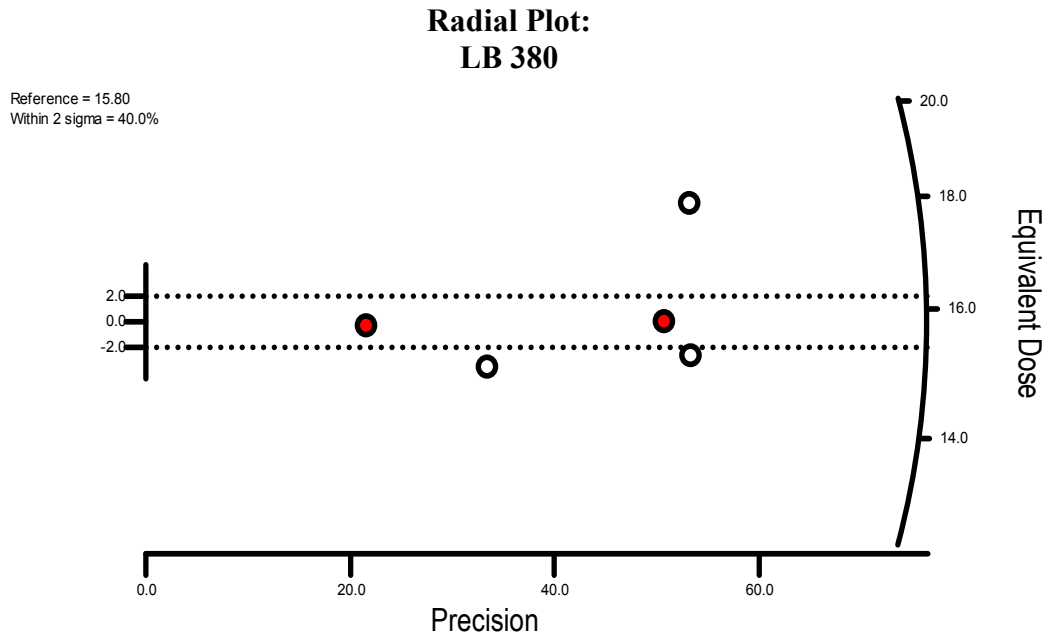


Figure: LB 380



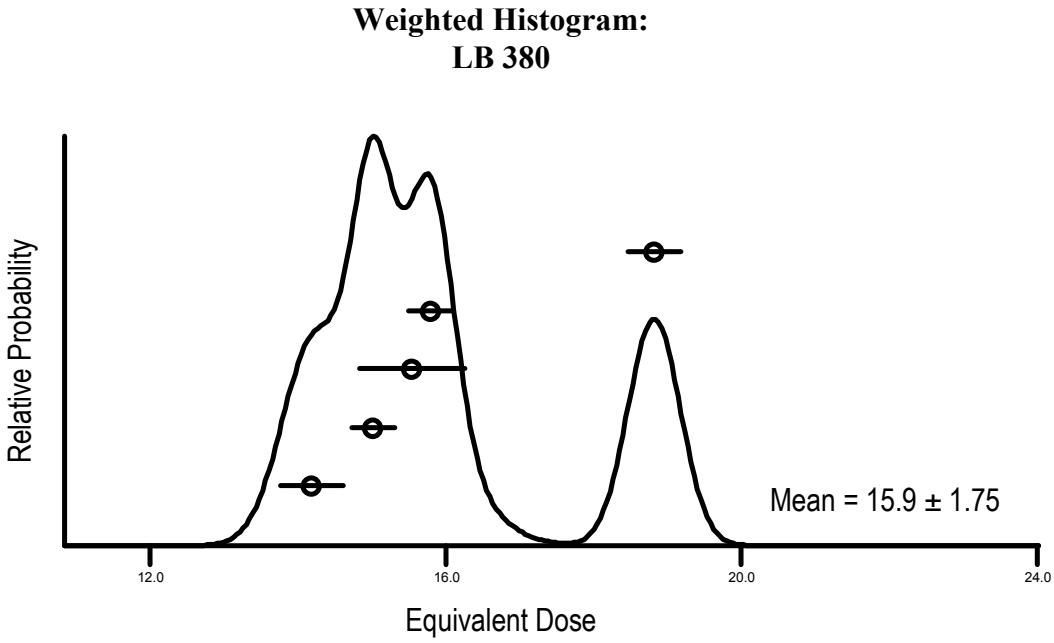
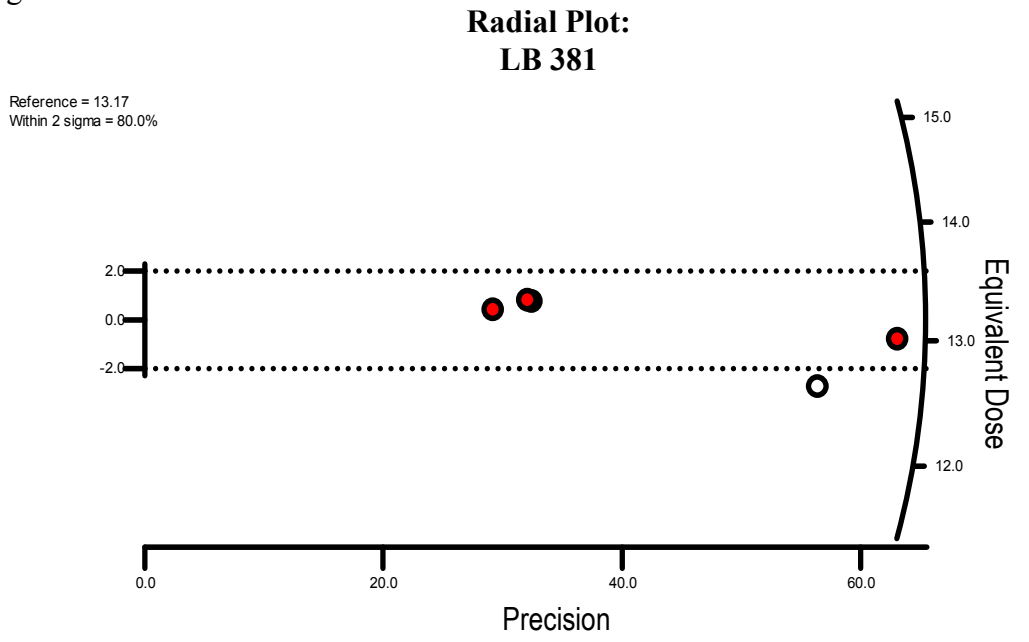


Figure: LB 381



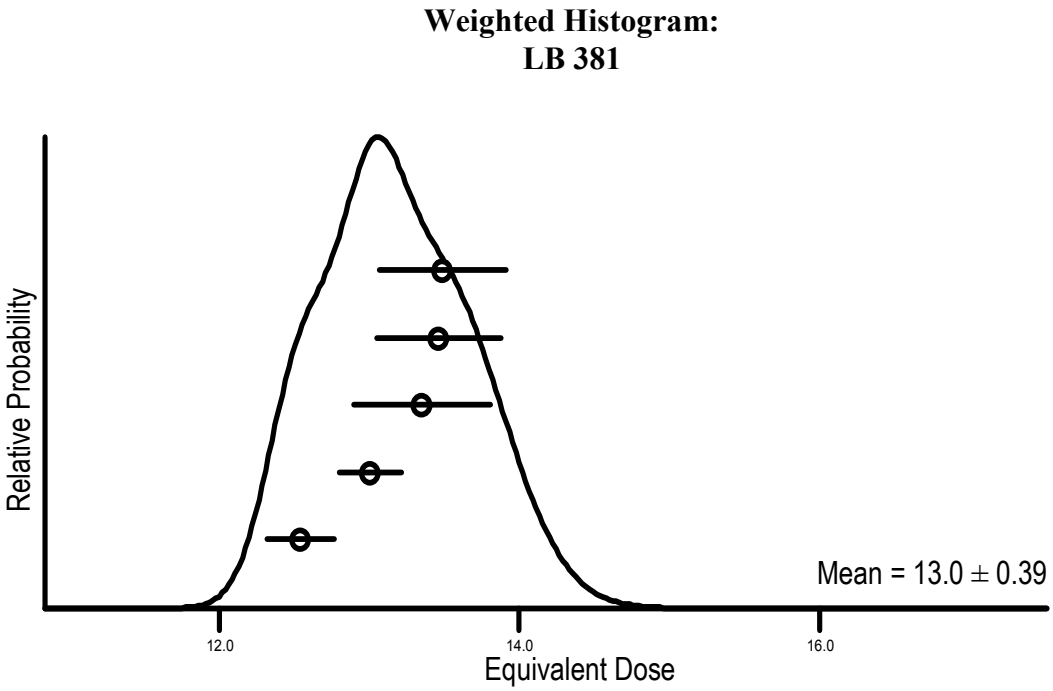
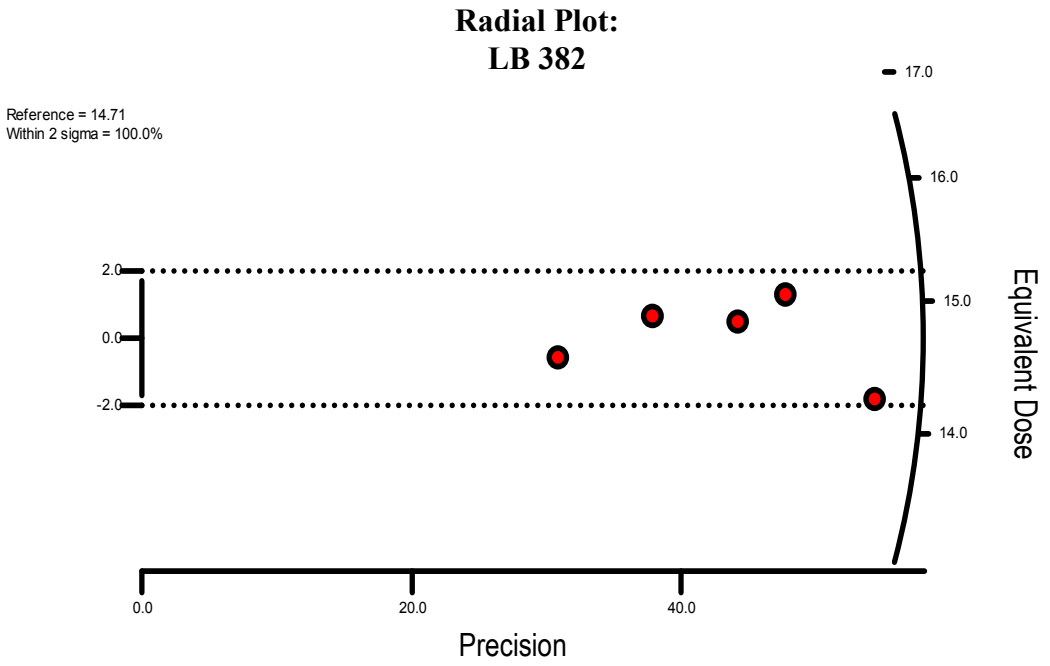


Figure: LB 382



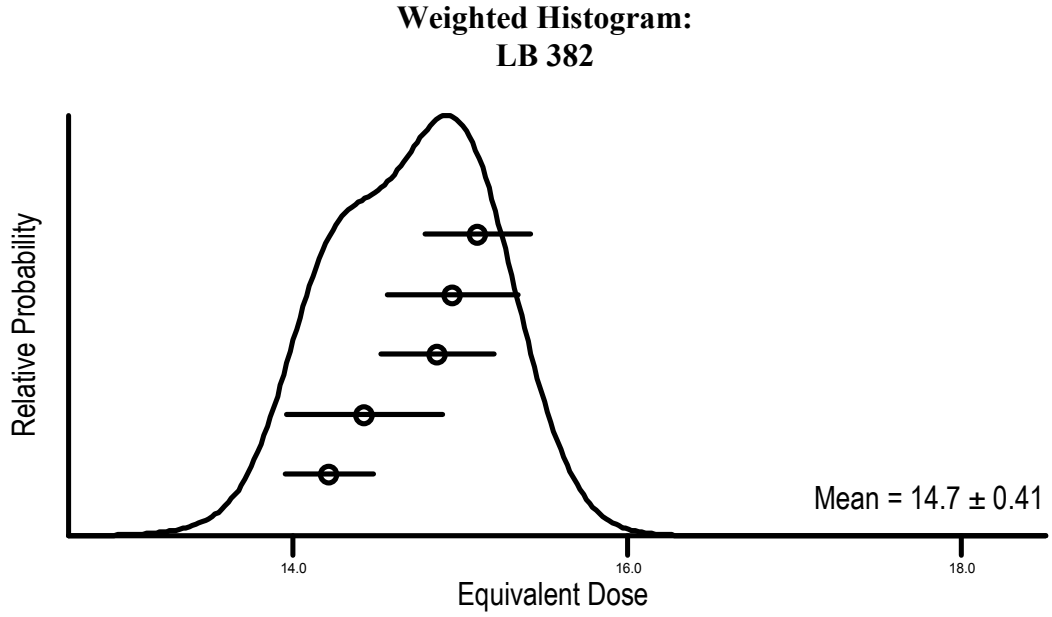
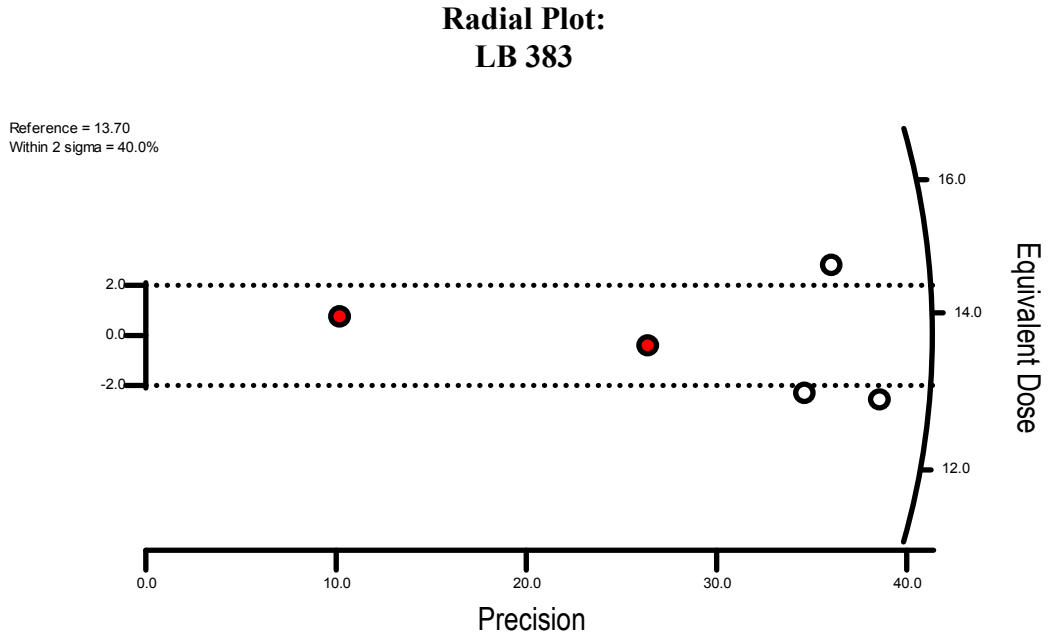


Figure LB 383



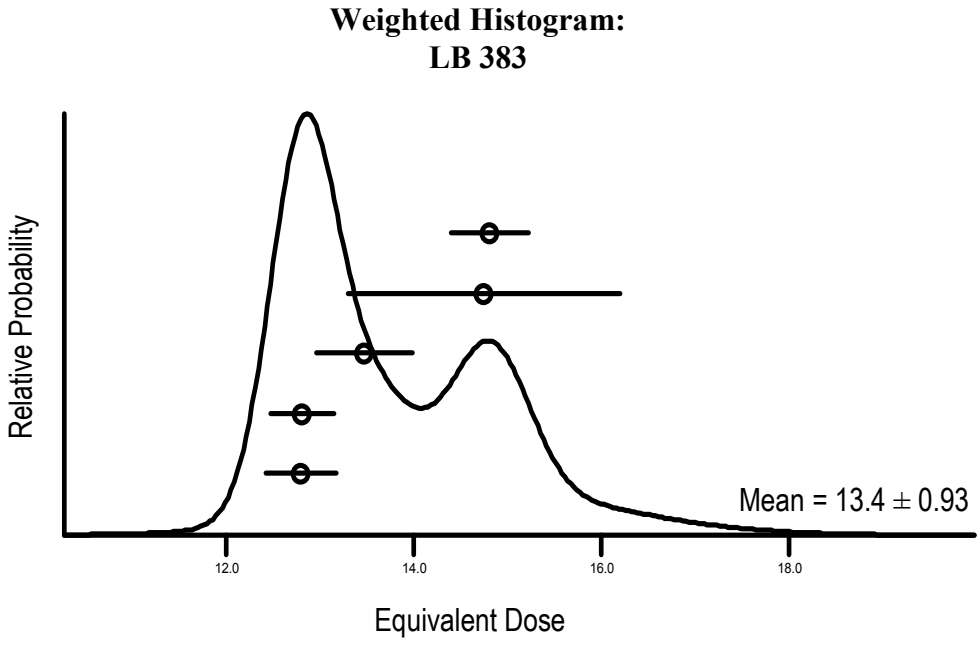
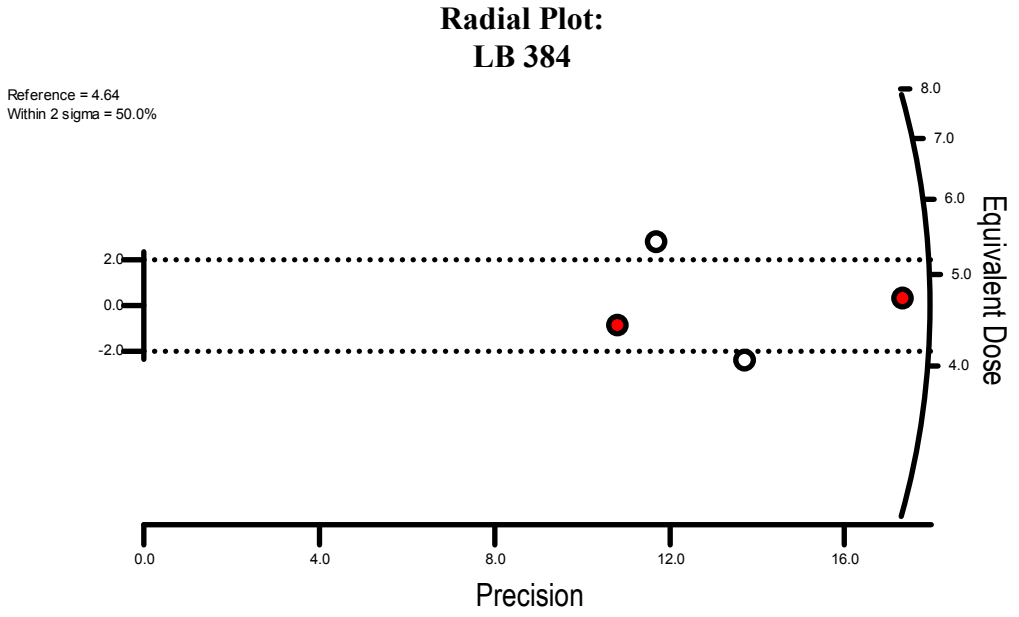


Figure LB 384



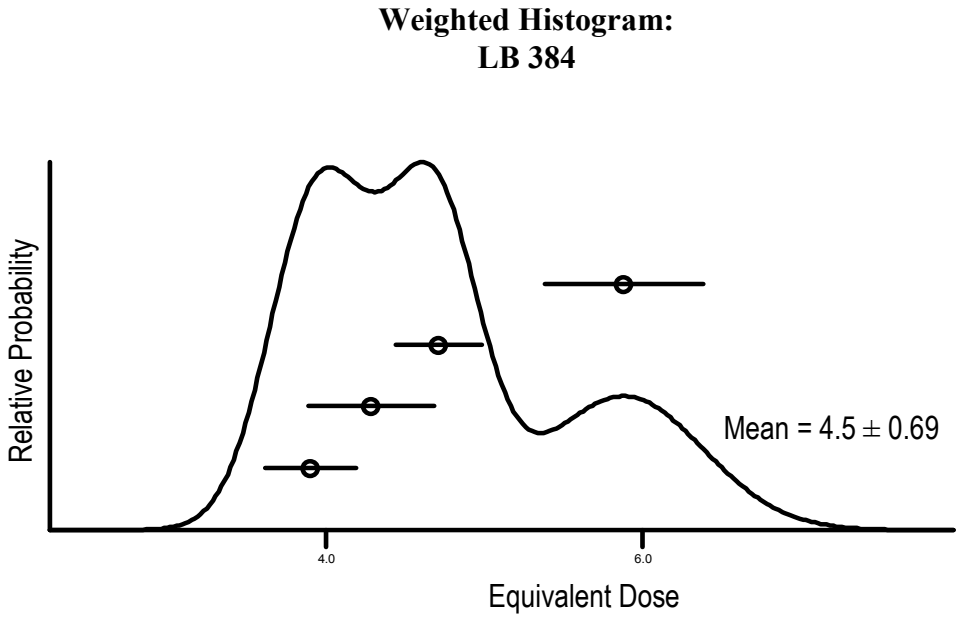
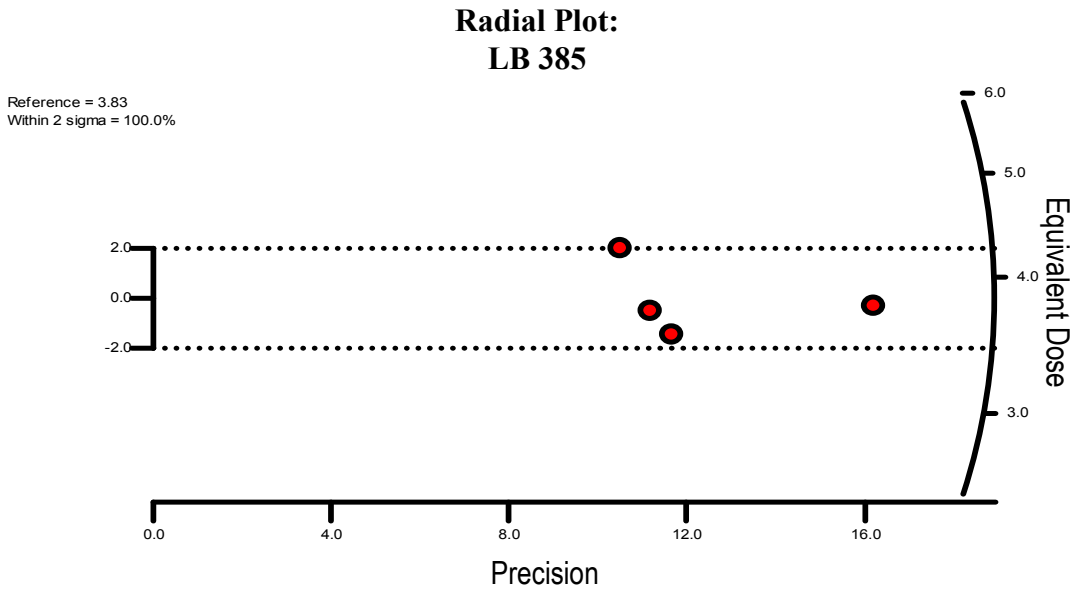
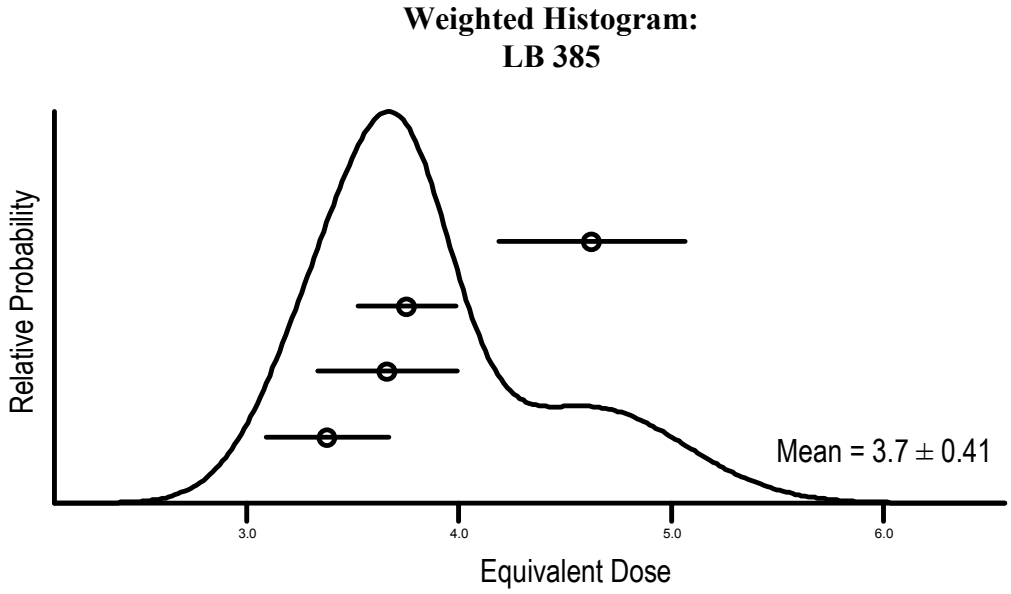


Figure LB 385





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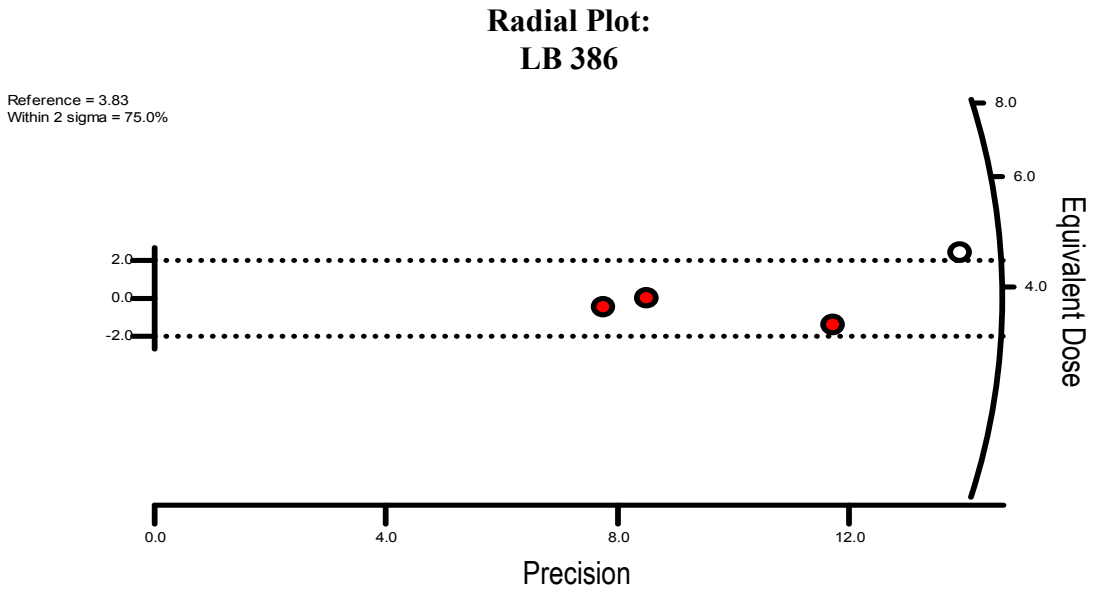


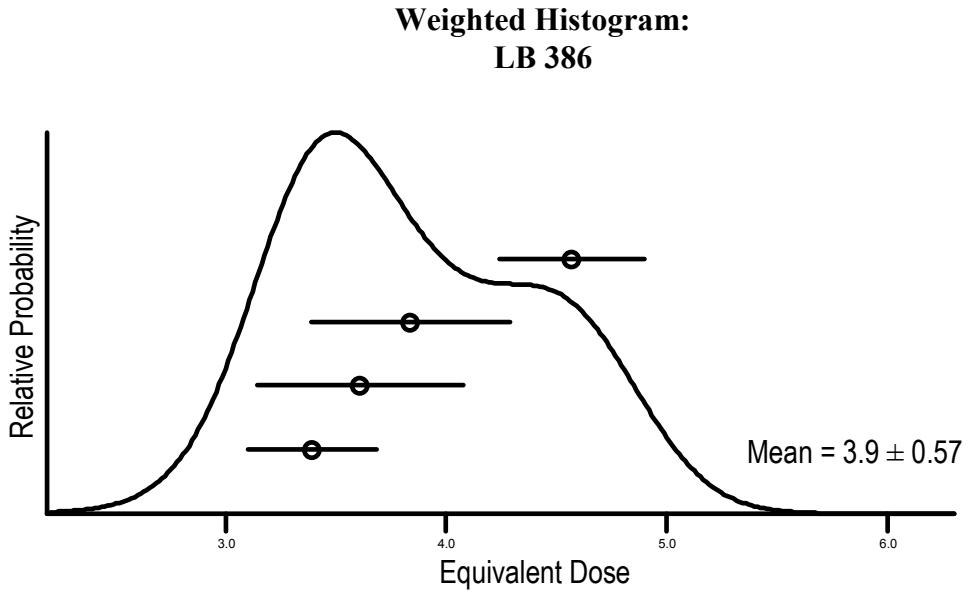
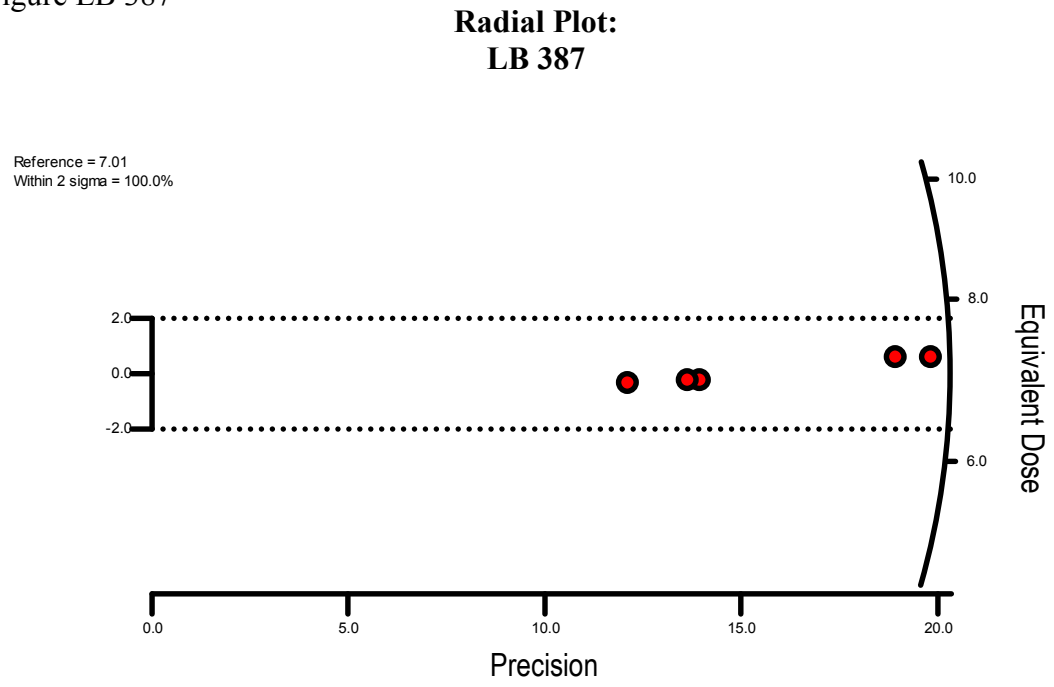


Figure LB 387



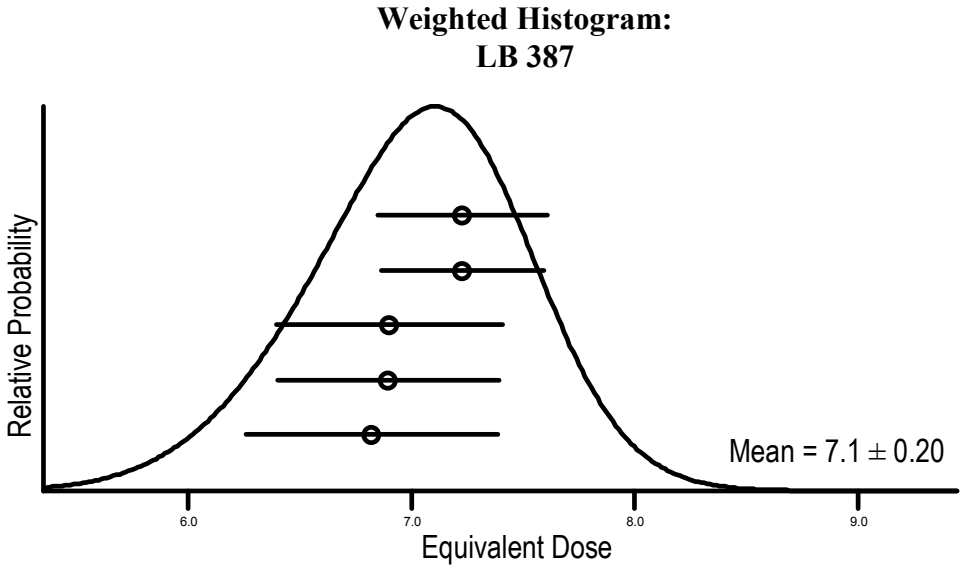
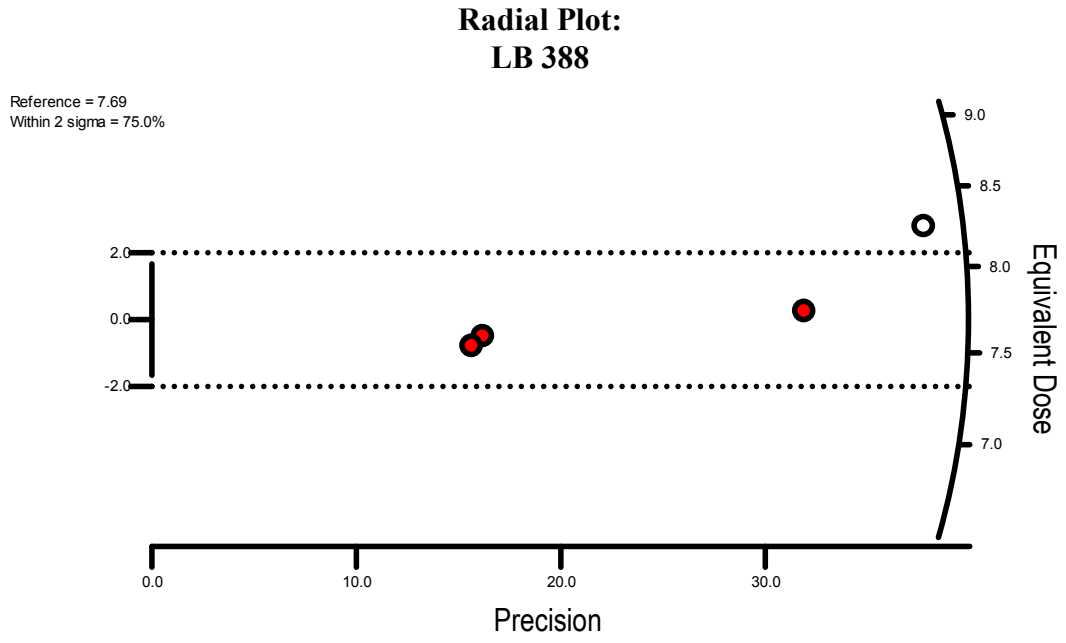


Figure LB 388



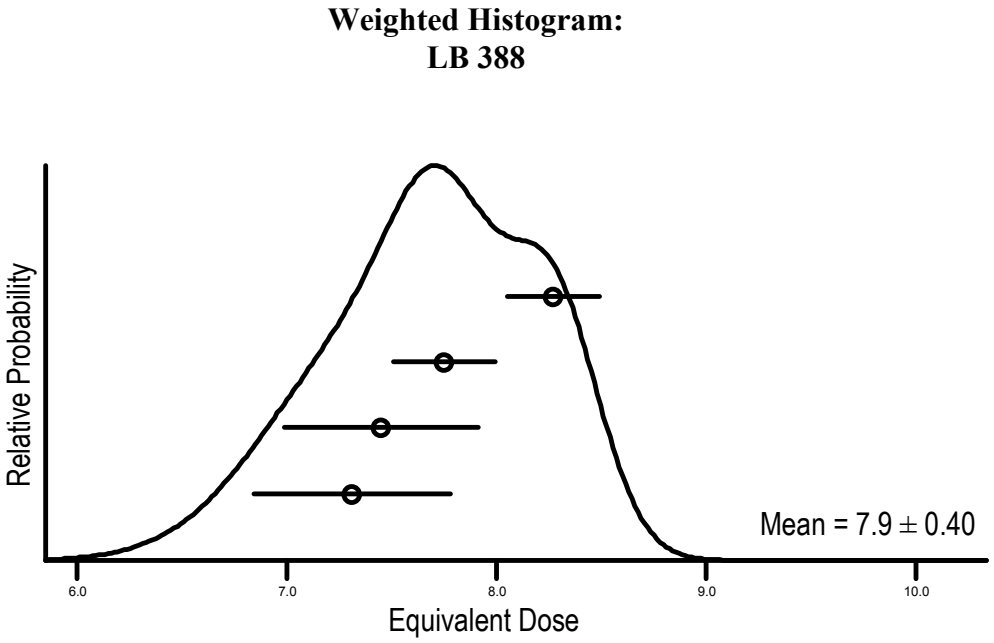
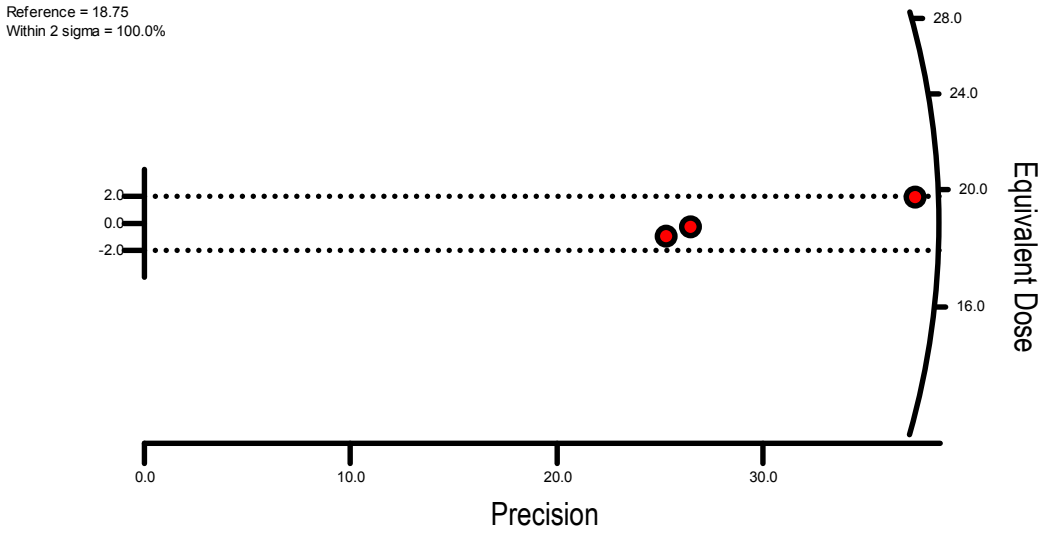


Figure LB 389

Radial Plot:
LB 389



Weighted Histogram:
LB 389

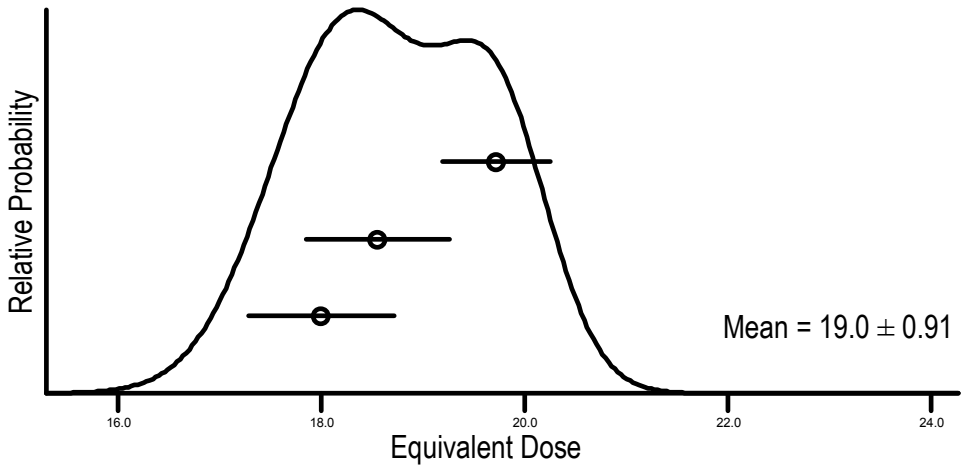
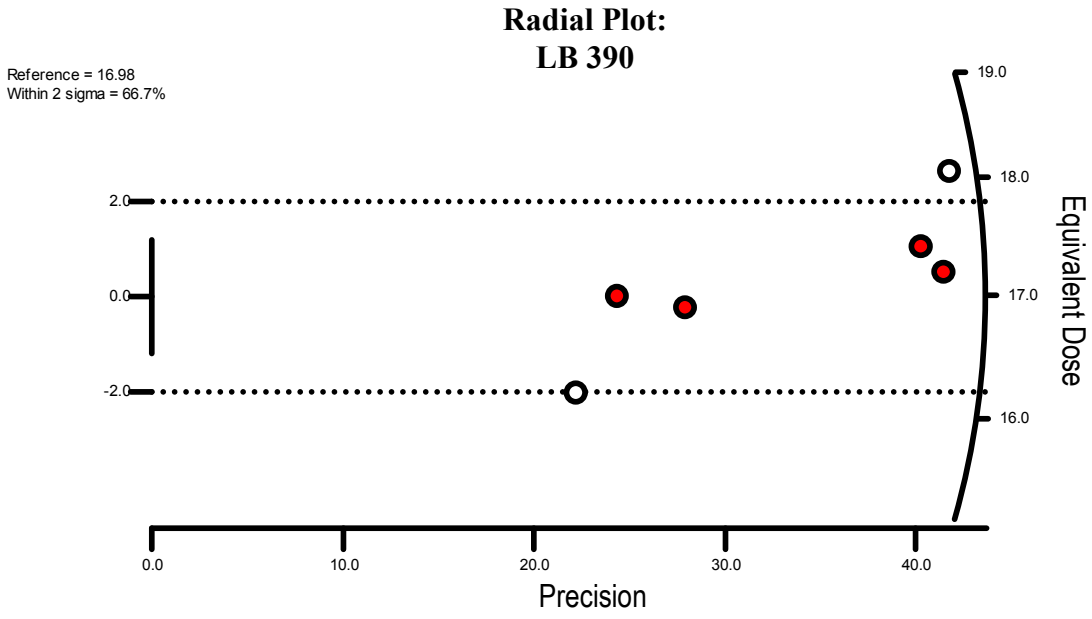


Figure LB 390



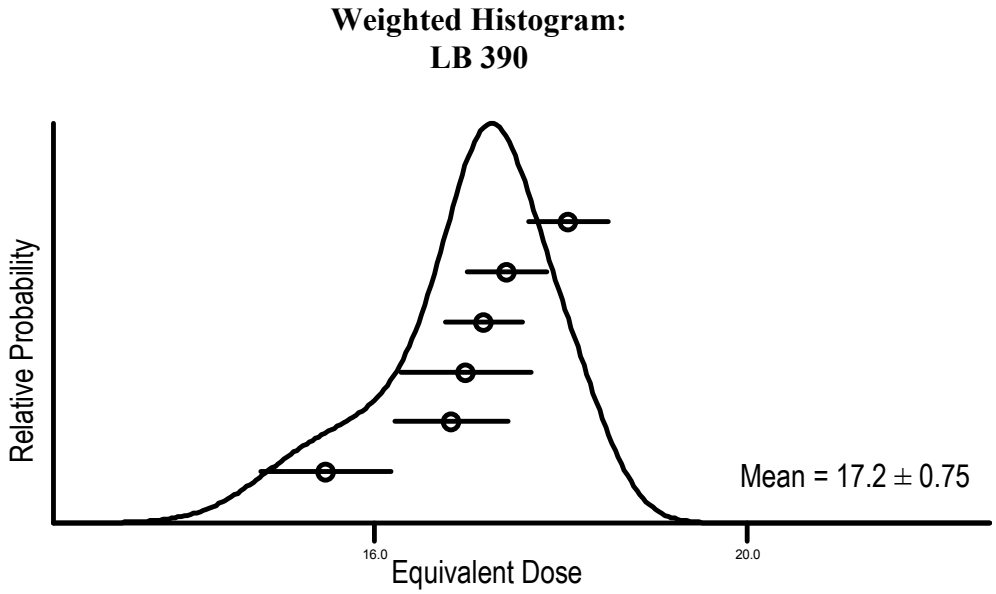
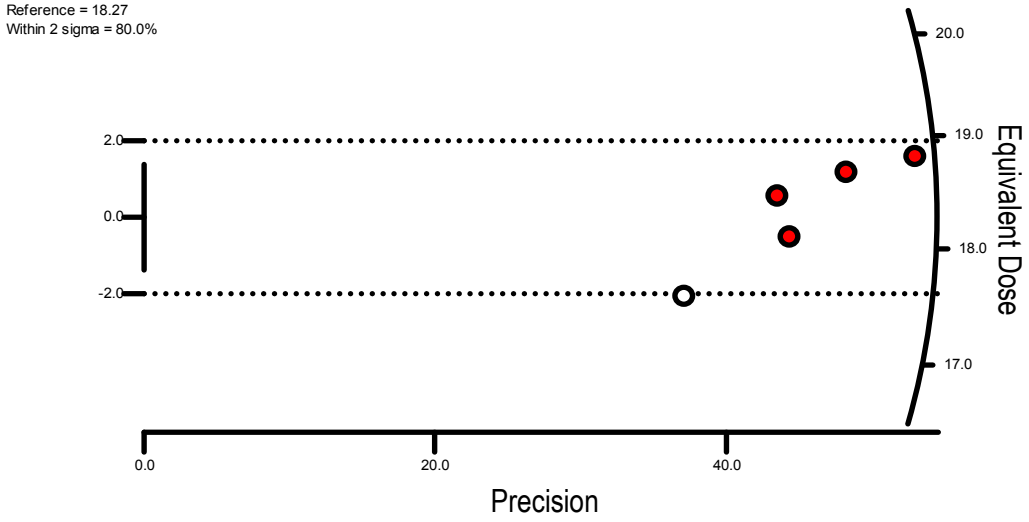


Figure LB 391

Radial Plot:
LB 391



Weighted Histogram:
LB 391

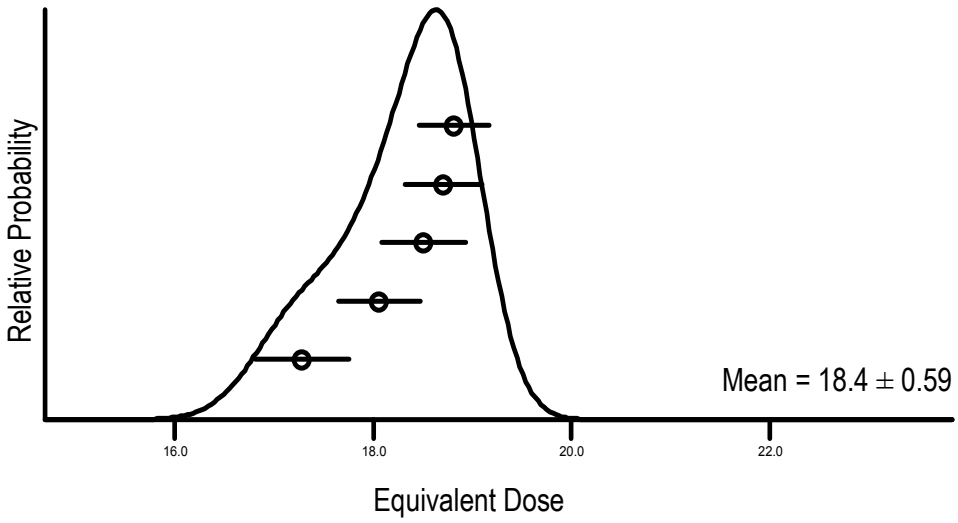
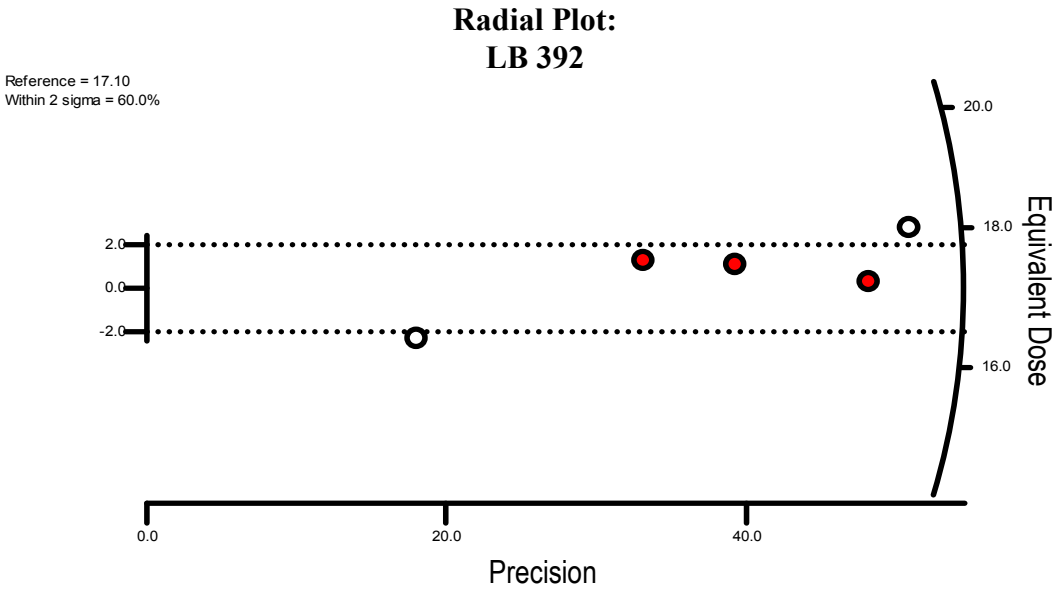


Figure LB 392



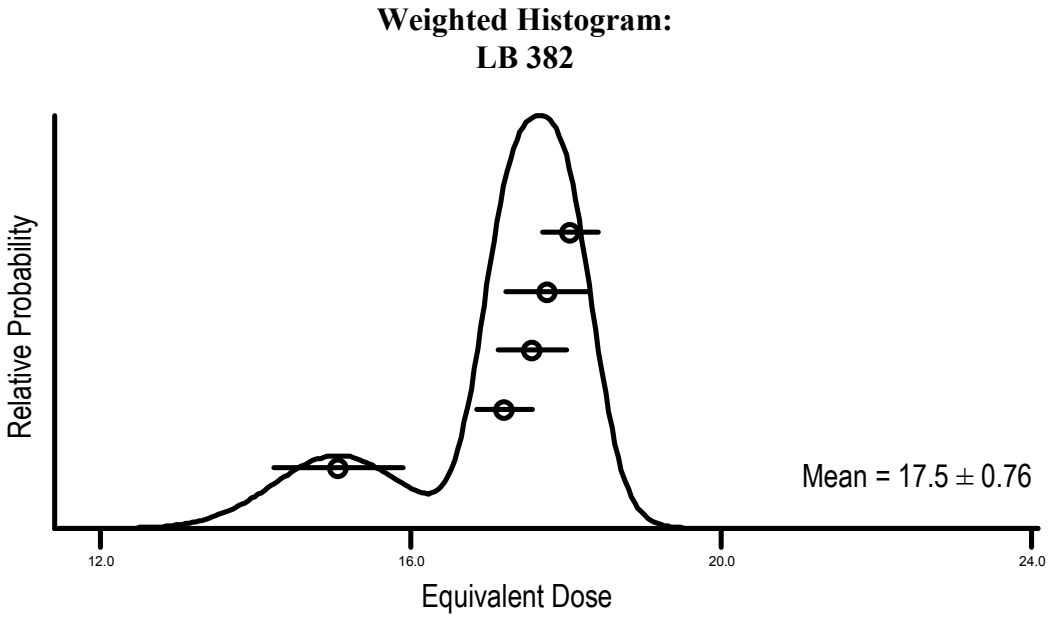
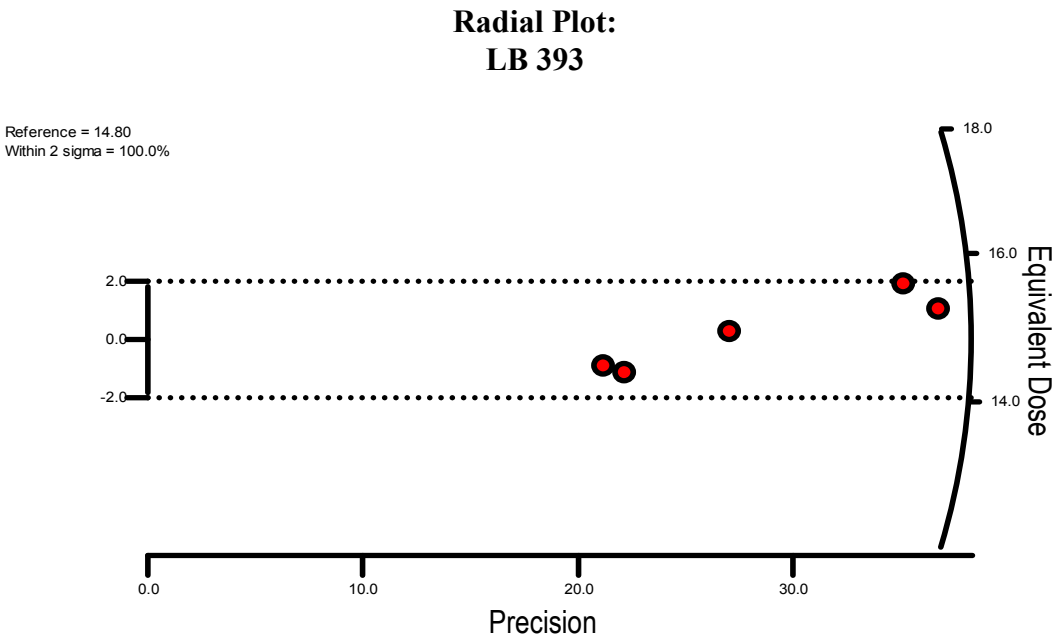


Figure LB 393



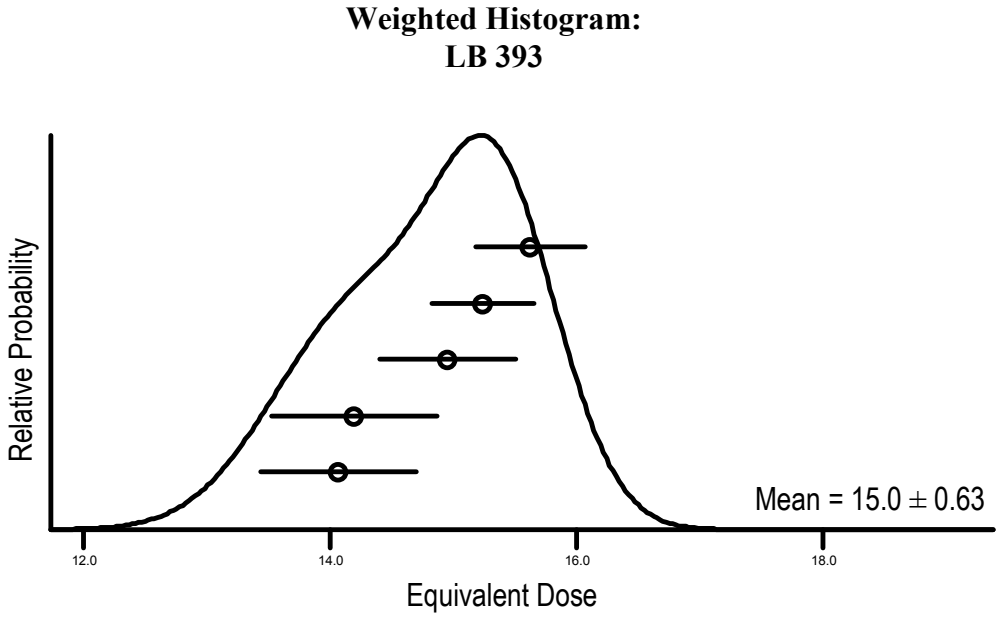
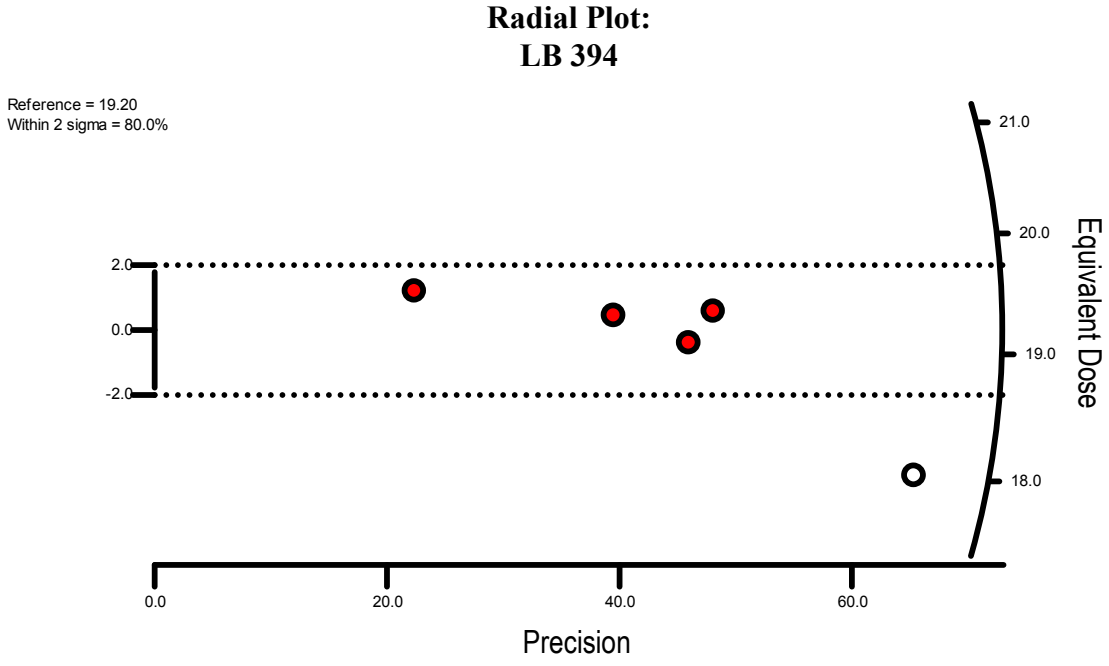


Figure LB 394



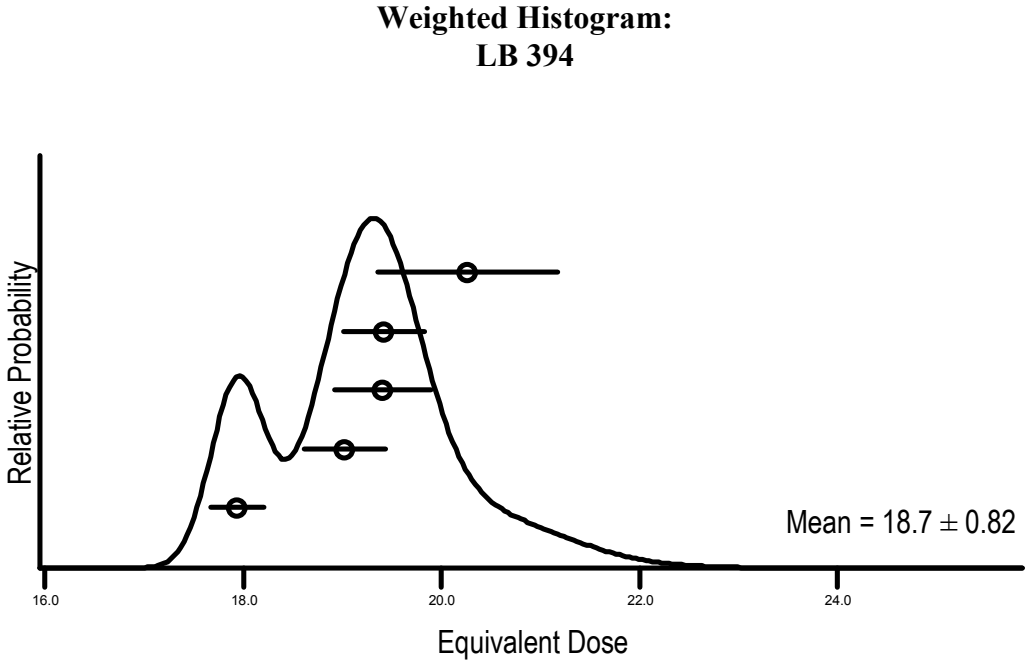
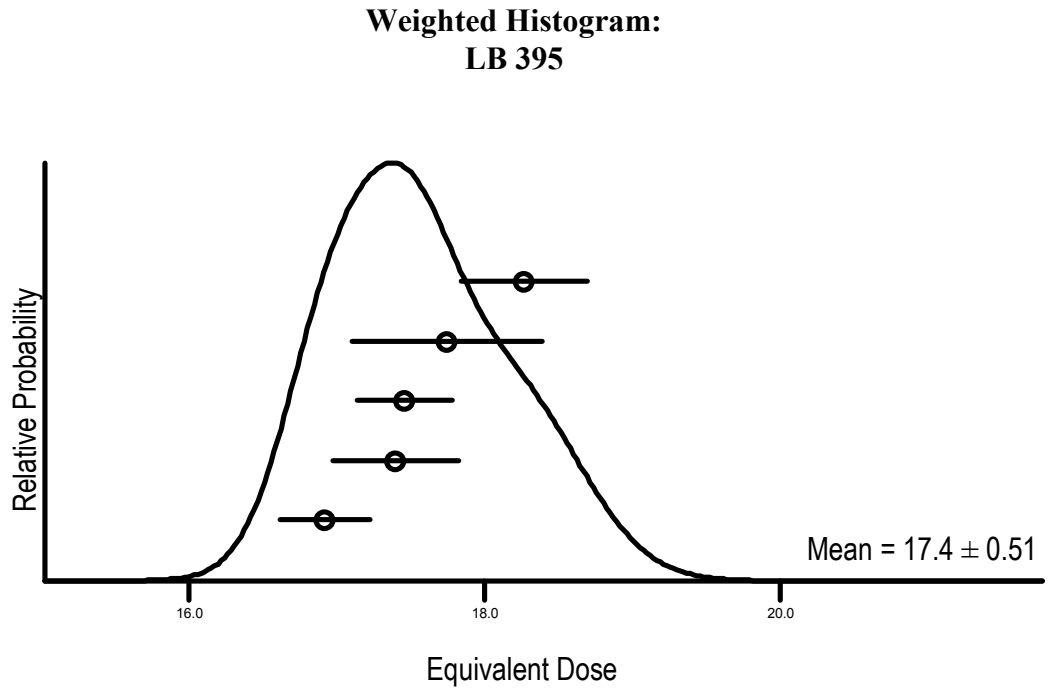


Figure LB 395



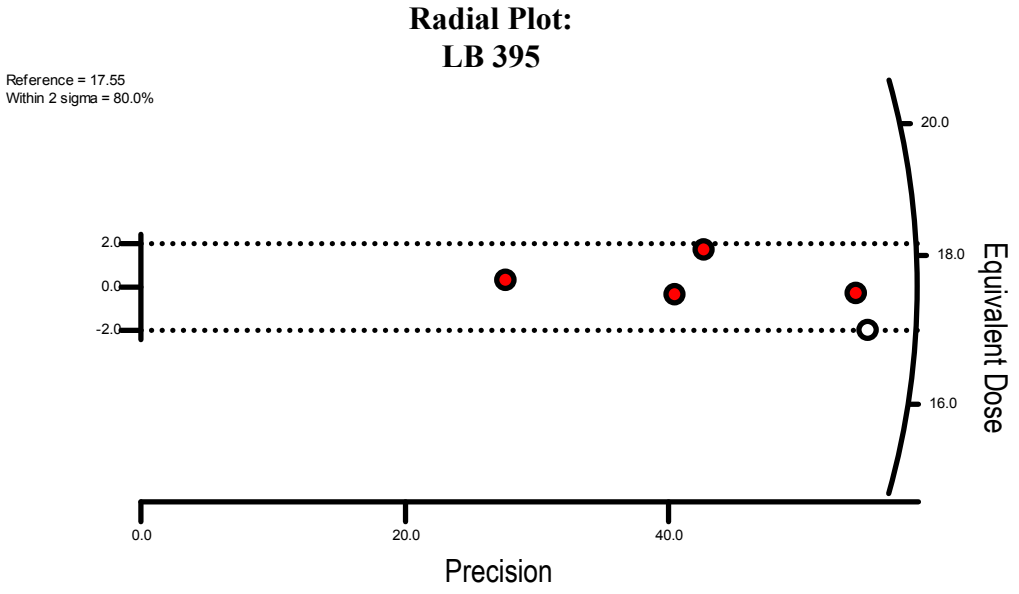
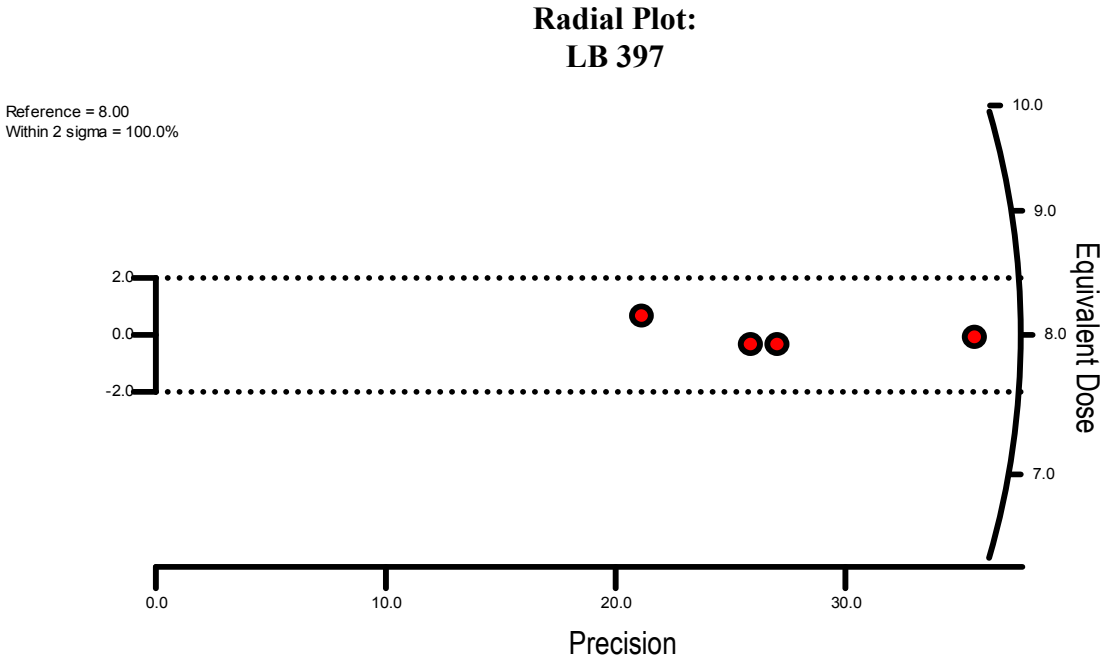


Figure LB 397



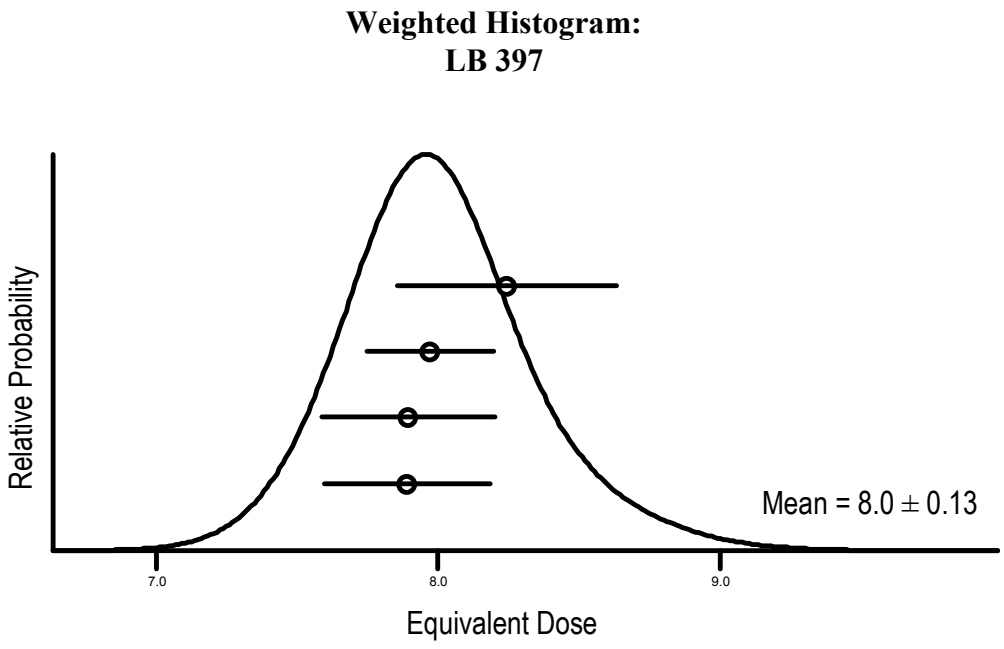
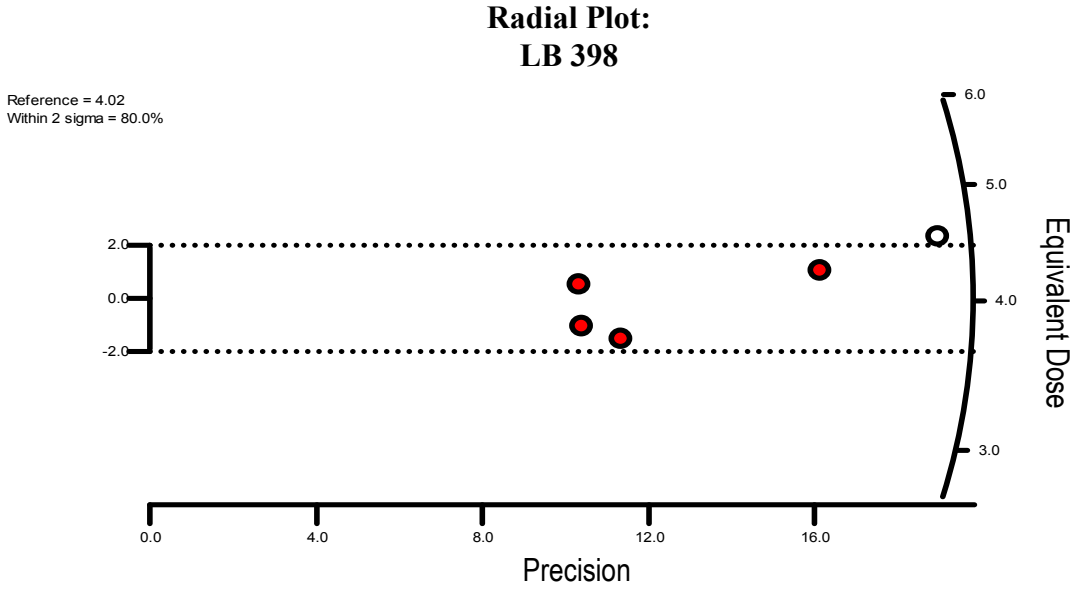


Figure LB 398



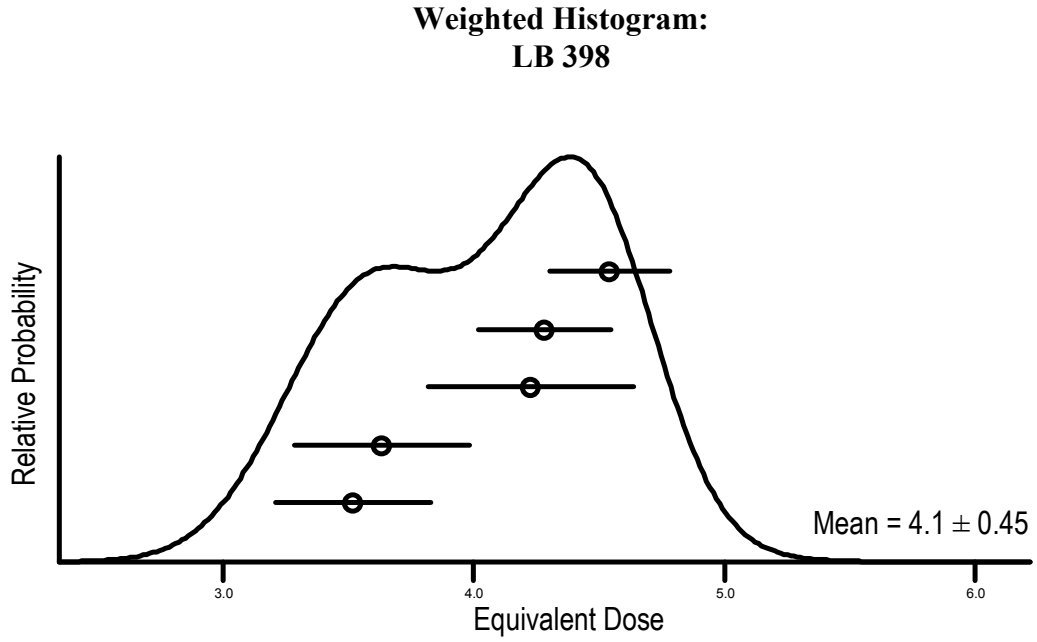
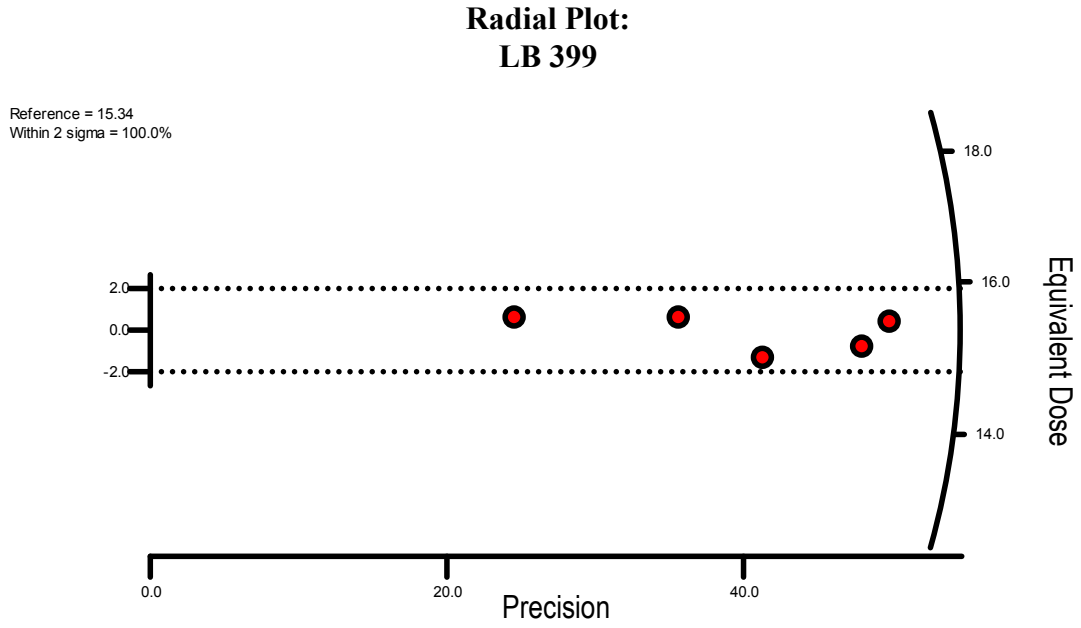


Figure LB 399



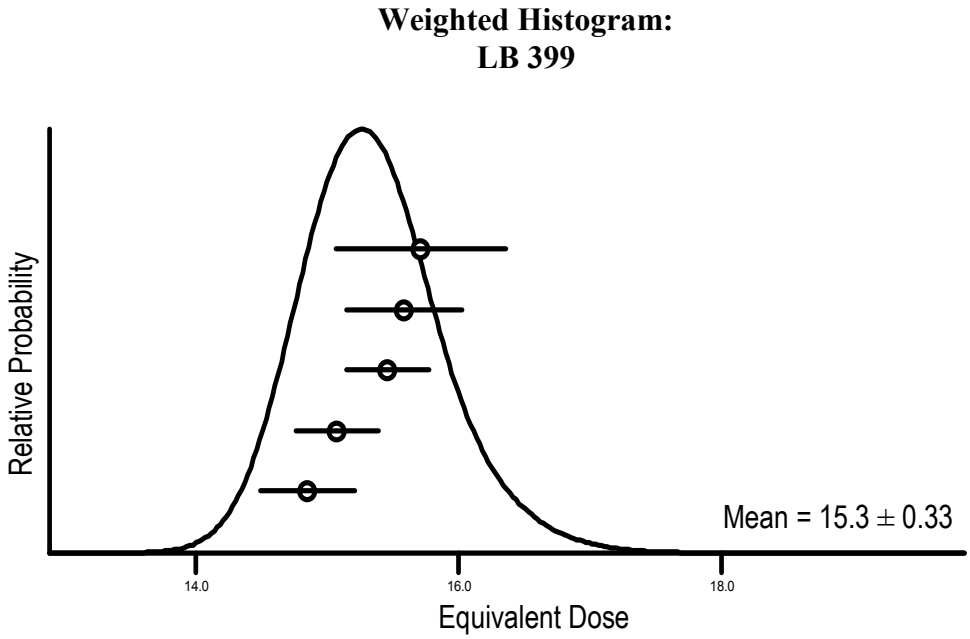
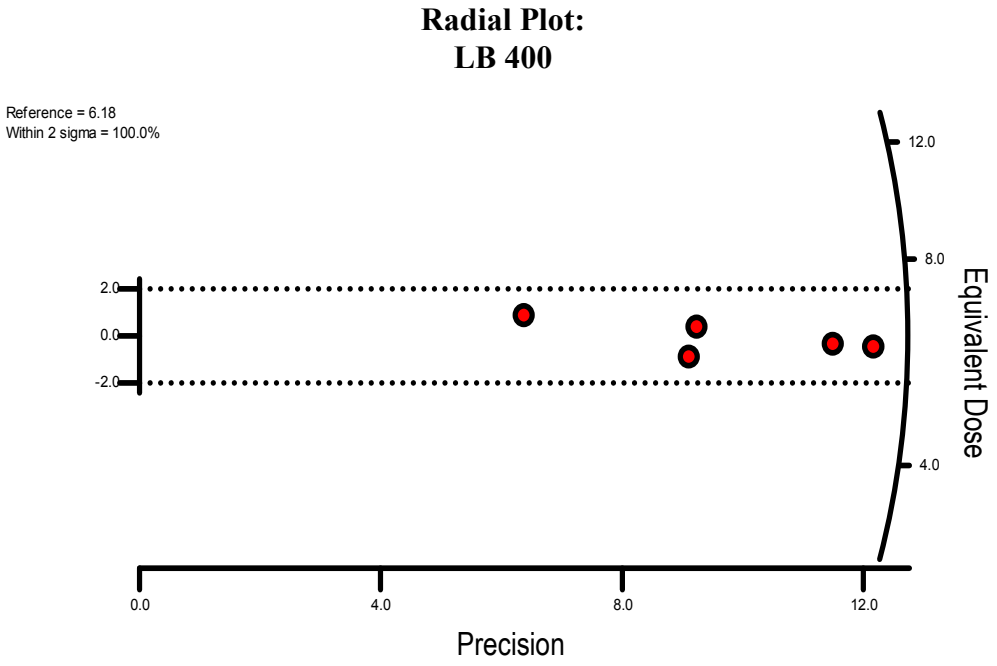


Figure LB 400



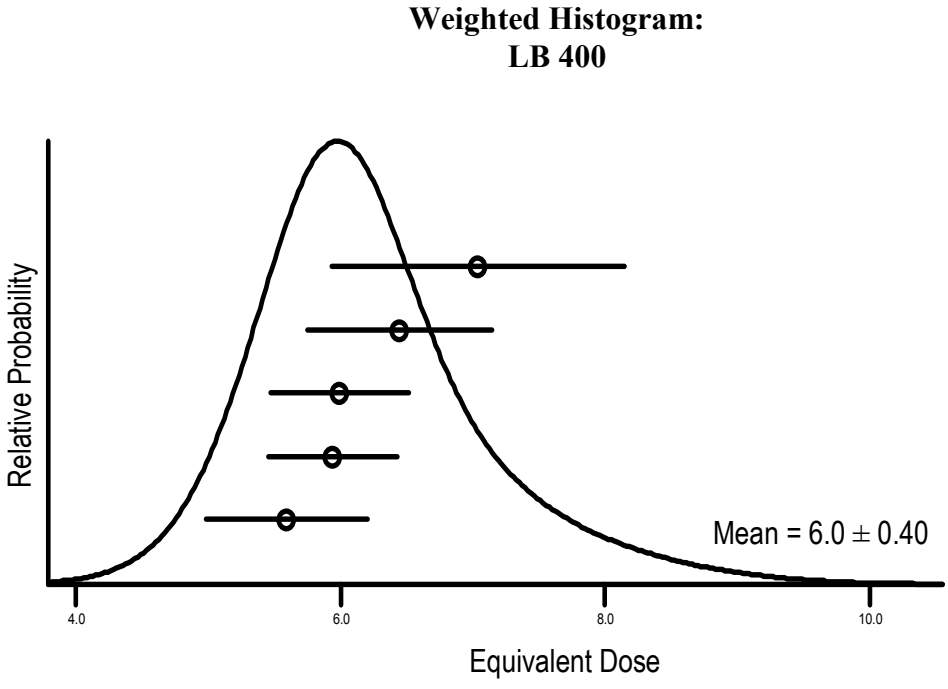
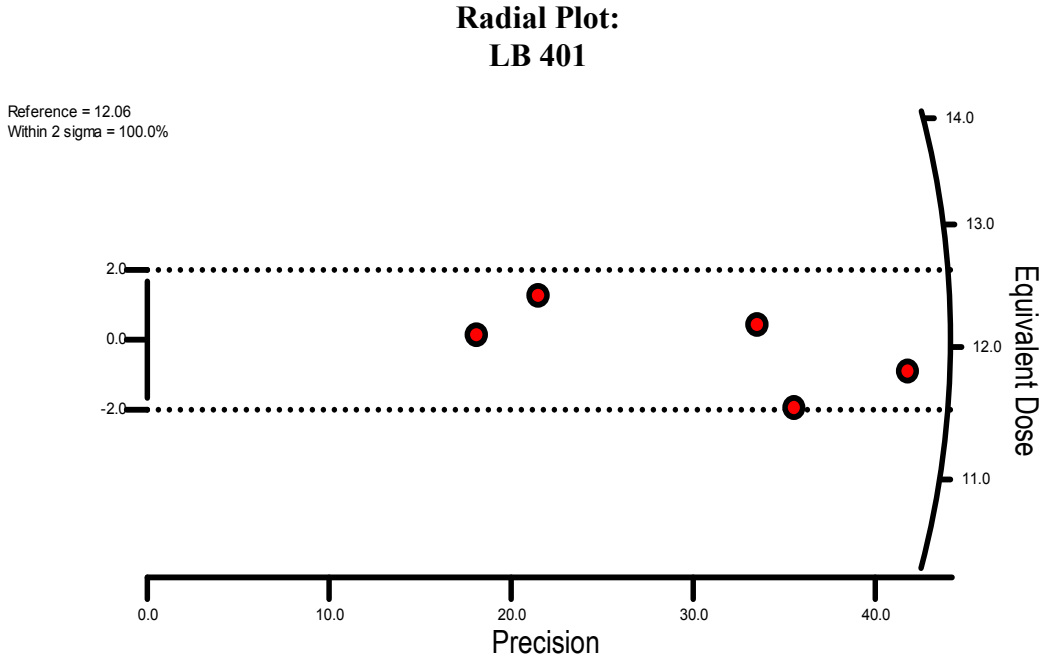


Figure LB 401



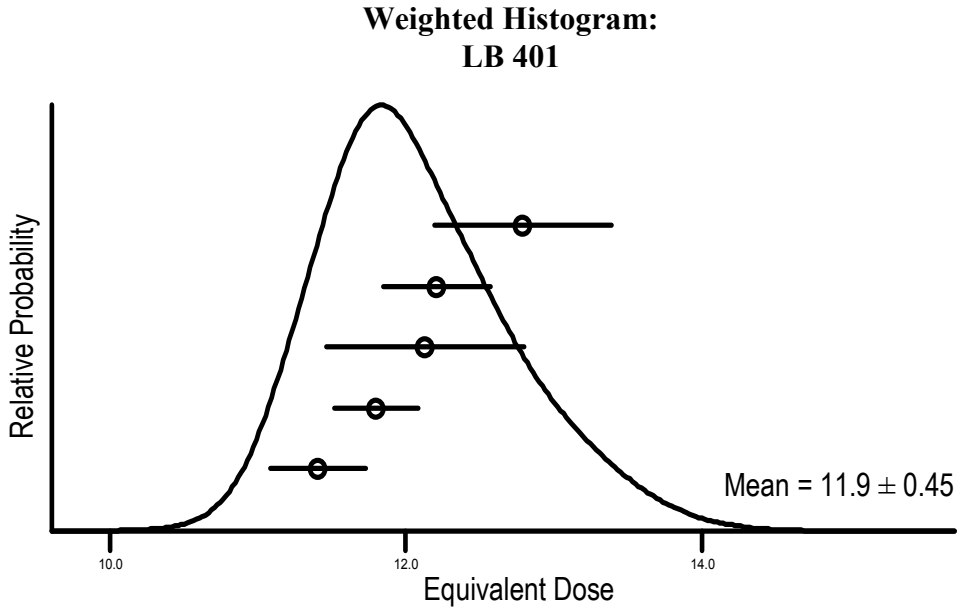
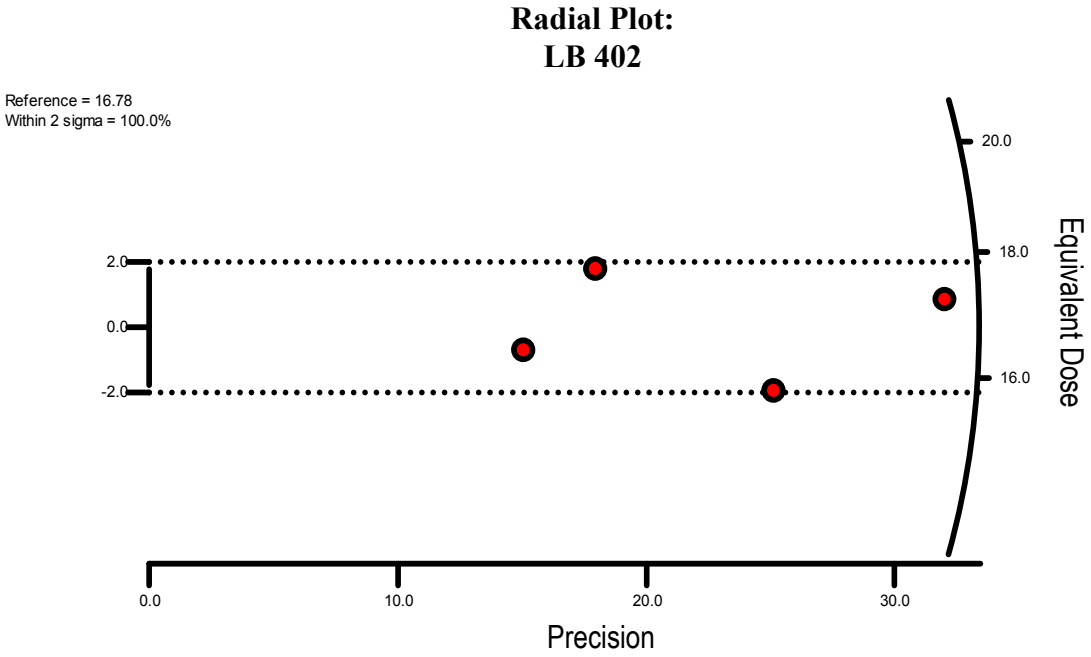
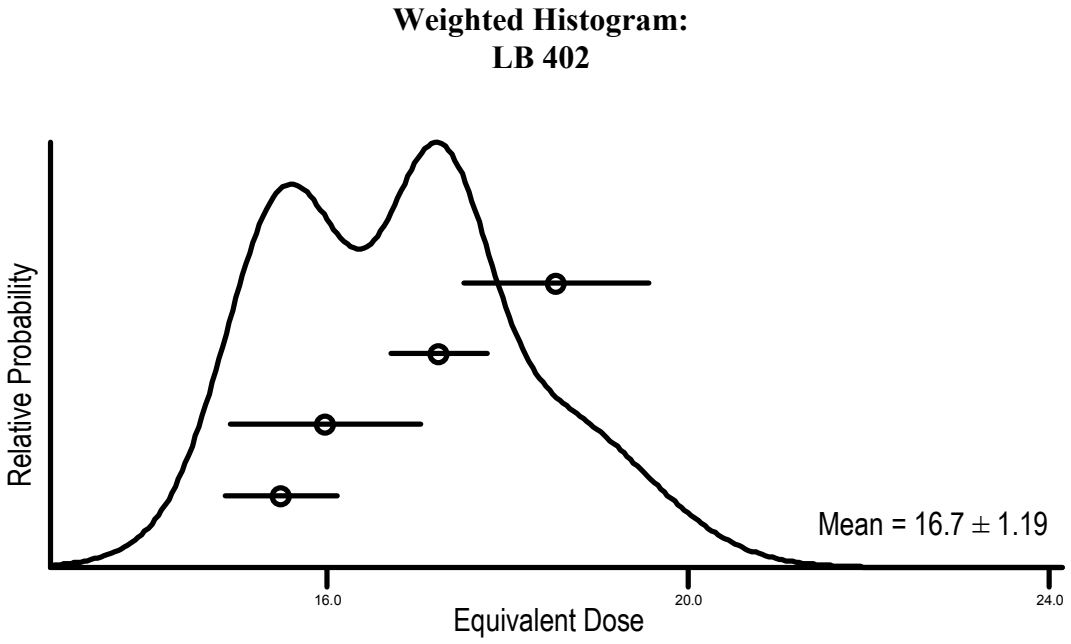


Figure LB 402





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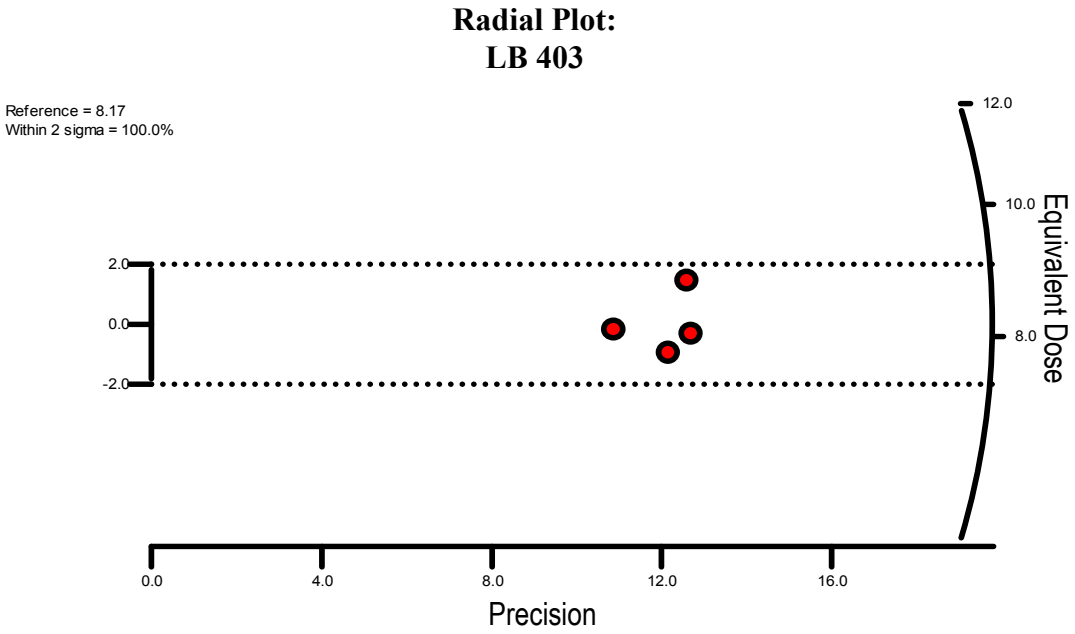


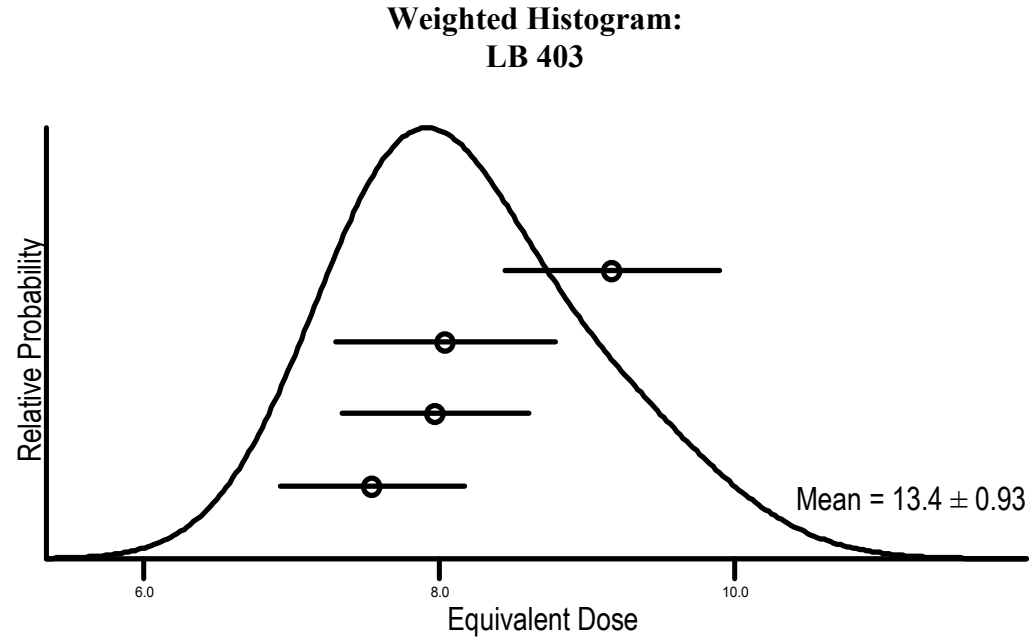
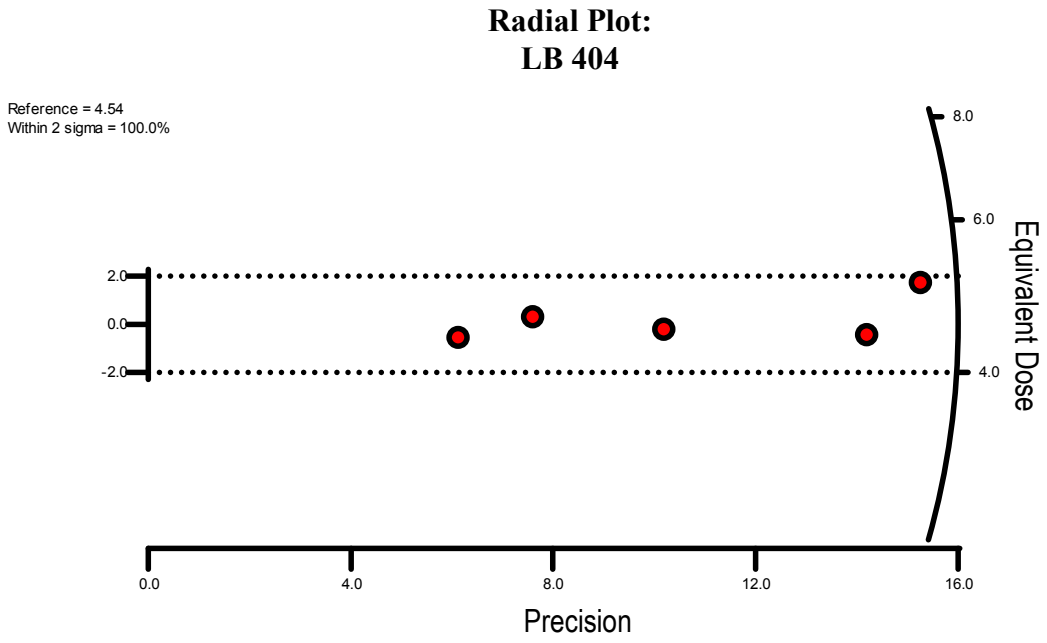


Figure LB 404



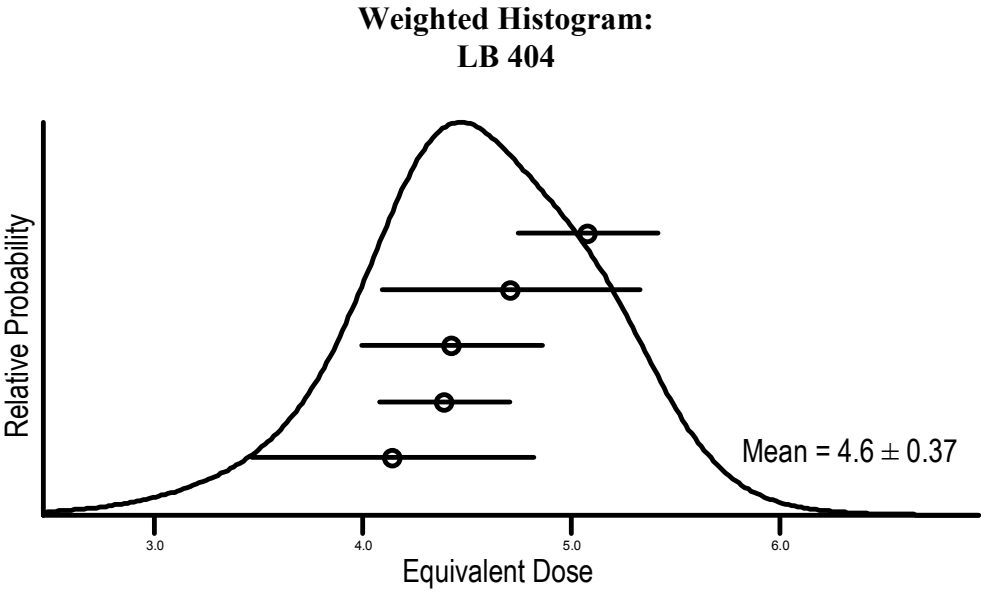
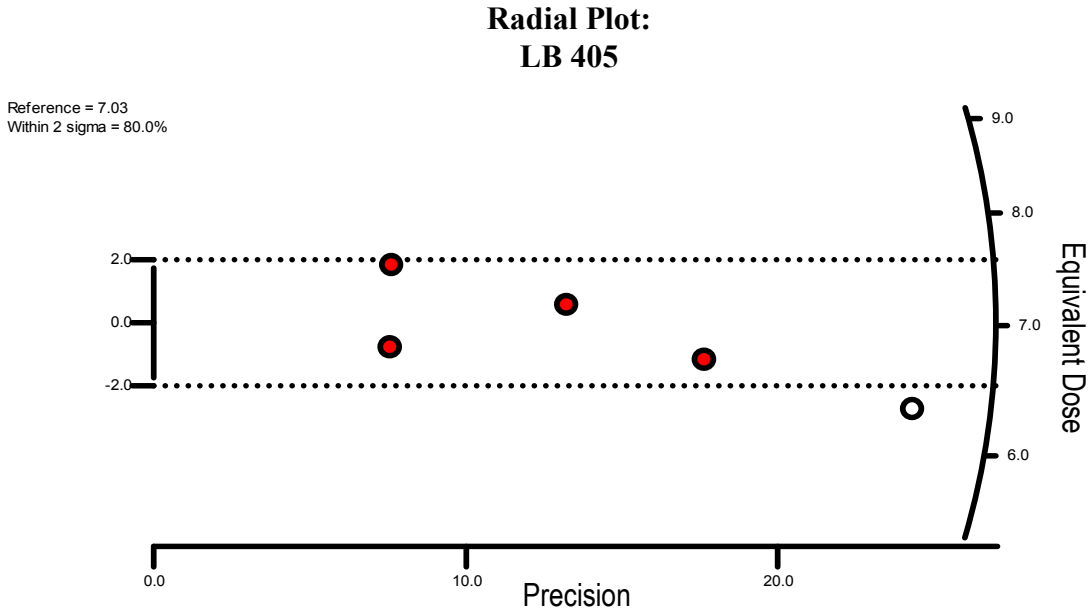


Figure LB 405



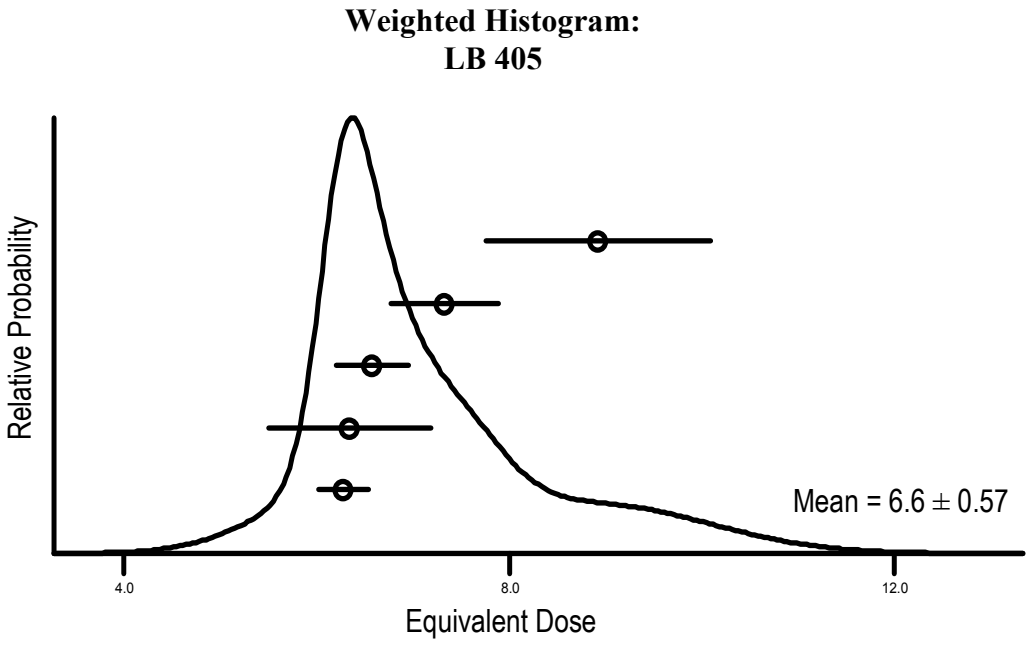
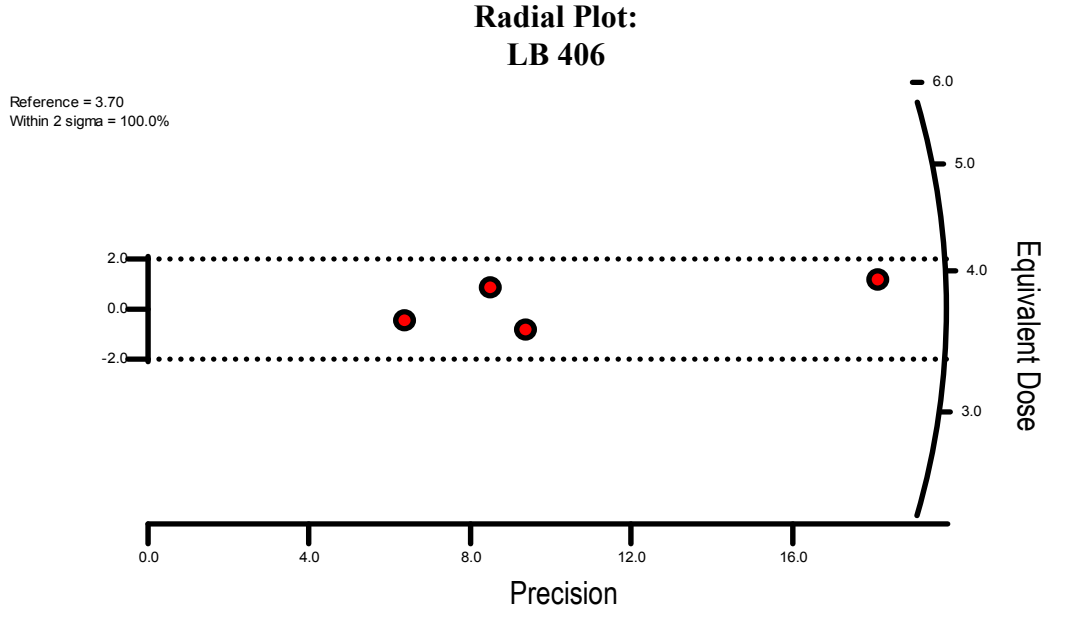


Figure LB 406



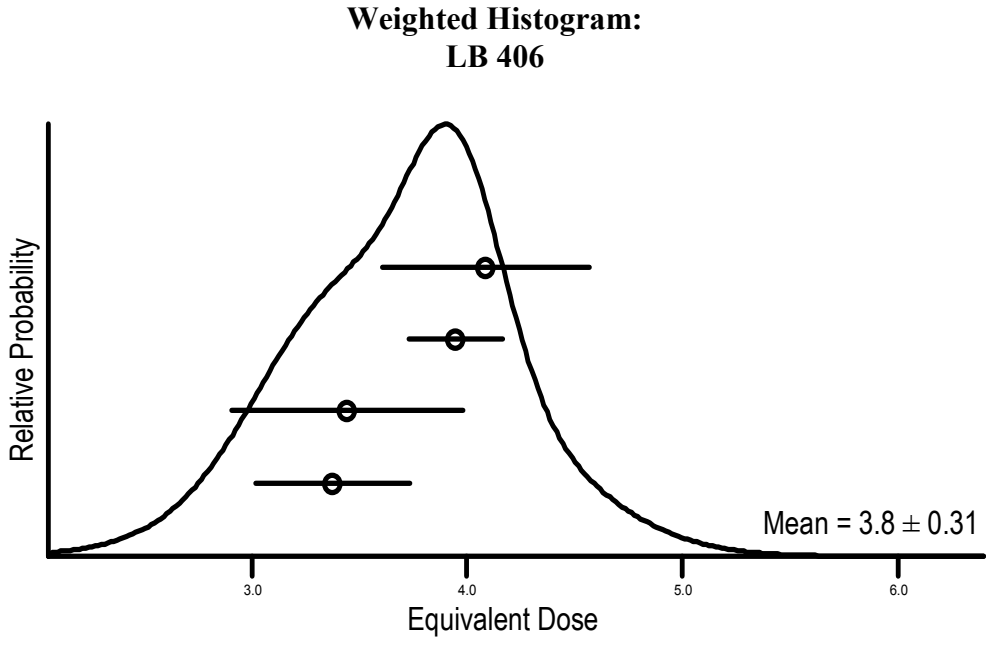
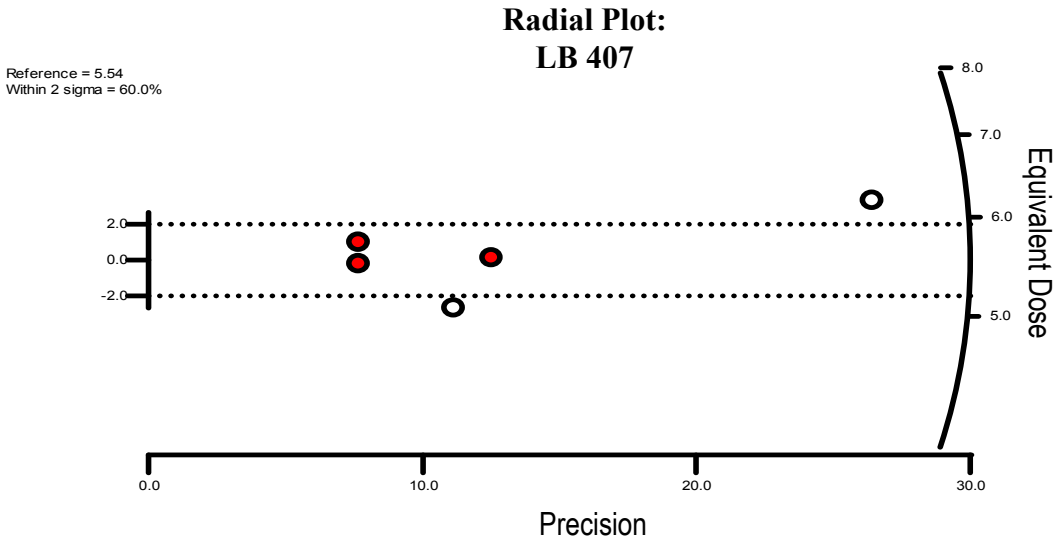


Figure LB 407



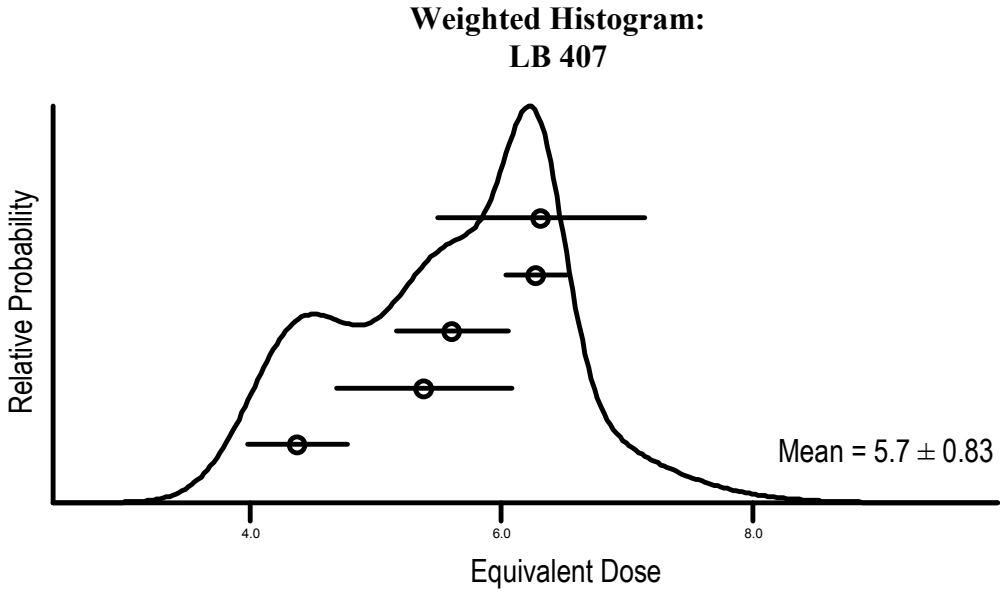
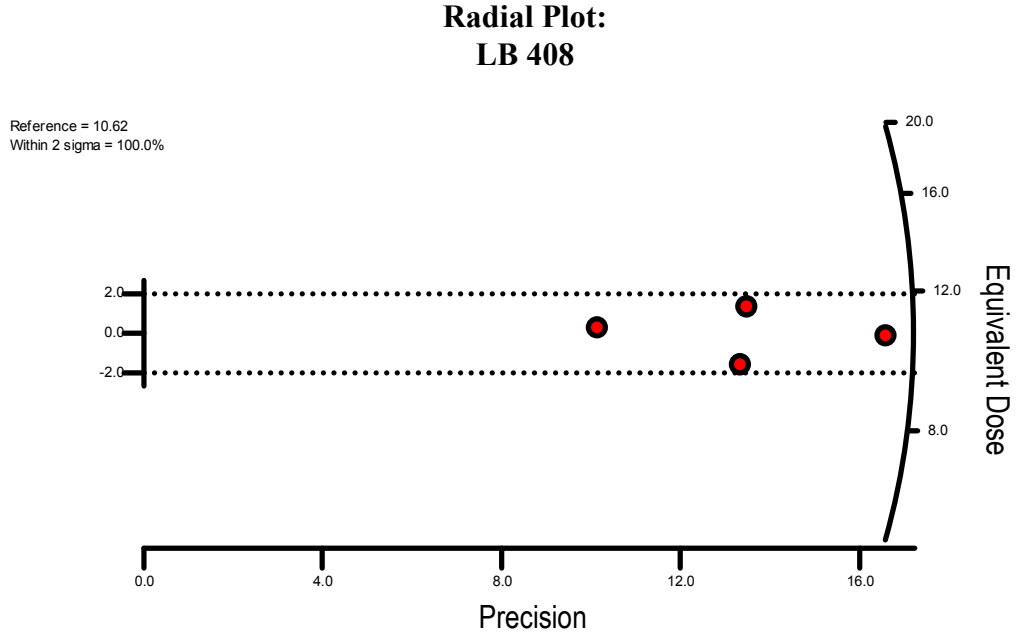


Figure LB 408



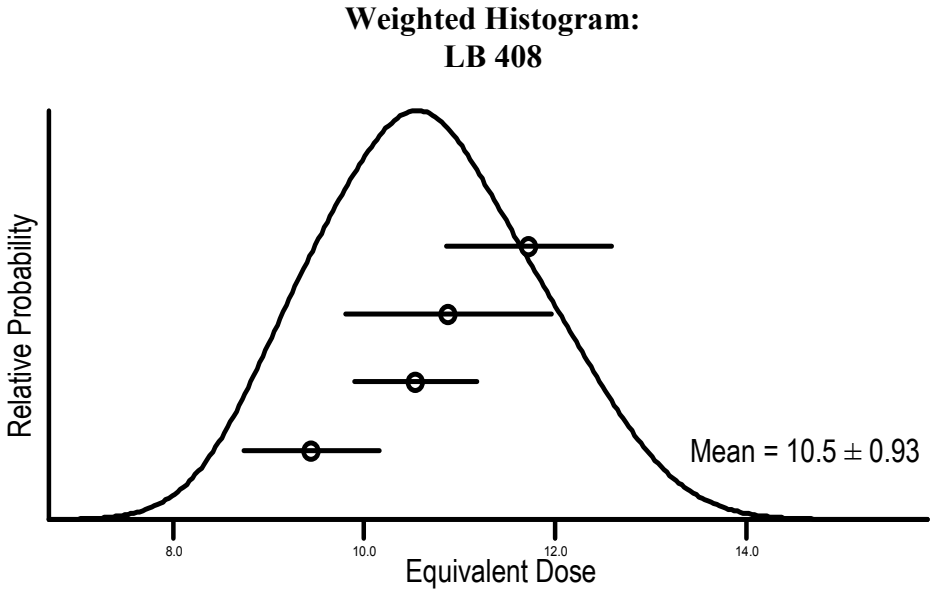
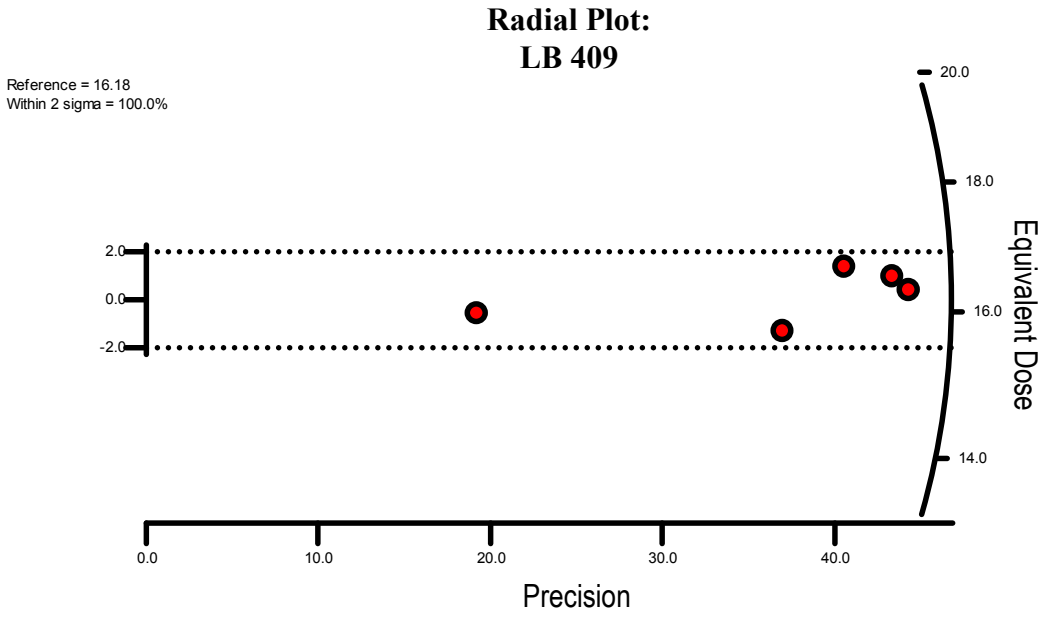
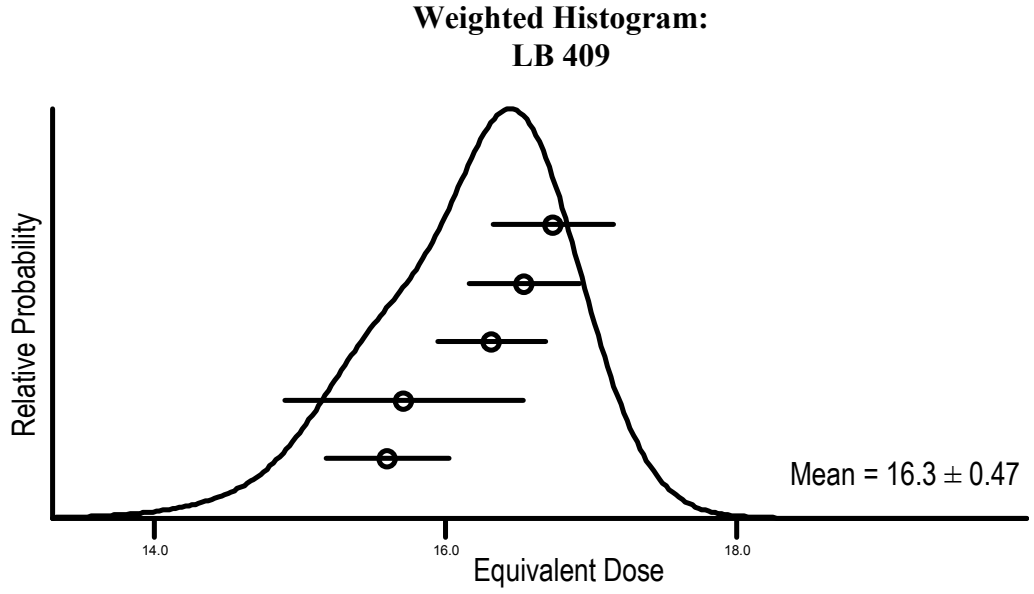


Figure LB 409





APPENDIX D

SAMPLE LOCATIONS AND MISCELLANEOUS DATA

Site Number	LB#	UTM Easting	UTM Northing	UTM Zone	Elevation (m)	Average Age (AD)	Error (in years)	Thickness (cm)	(D) Dry Sample Wt	(S) Saturated Sample Wt	H20 Absorption
ISO 1	403	580263	3884148	11	272.098	1560	42.8	0.49	16.834	18.809	0.117322
ISO 2	408	580312	3884150	11	272.098	1596	34.92	0.53	7.069	7.864	0.112463
ISO 3	409	580264	3884153	11	272.098	1352	32.71	0.47	5.017	5.423	0.080925
SBR-1997	394	589196	3889228	11	284.6832	1232	35.79	0.54	2.481	3.011	0.213624
SBR-1997	395	589196	3889228	11	284.6832	1358	24.52	0.6	10.626	11.501	0.082345
SBR-3570	378	581274	3883957	11	288.3408	1328	35.35	0.4	6.012	6.495	0.080339
SBR-3570	387	581270	3883968	11	290.4744	1769	17.62	0.71	16.53	18.547	0.122021
SBR-3570	388	581270	3883968	11	290.4744	1658	21.03	0.63	18.003	19.37	0.075932
SBR-3570	389	581270	3883968	11	290.4744	1286	33	0.52	3.504	4.031	0.1504
SBR-3570	390	581270	3883968	11	290.4744	1303	35.78	0.45	4.094	4.702	0.14851
SBR-3570	391	581270	3883968	11	290.4744	1246	33.9	0.4	2.444	2.818	0.153028
SBR-3570	392	581270	3883968	11	291.6936	1248	38.21	0.35	1.845	1.985	0.075881

Site Number	LB#	UTM Easting	UTM Northing	UTM Zone	Elevation (m)	Average Age (AD)	Error (in years)	Thickness (cm)	(D) Dry Sample Wt	(S) Saturated Sample Wt	H20 Absorption
SBR-3571	379	581295	3883958	11	287.7312	1345	27.35	0.72	17.075	19.06	0.116252
SBR-3571	380	581295	3883958	11	287.7312	1405	26.25	0.64	5.751	6.358	0.105547
SBR-3571	381	581353	3883984	11	287.4264	1404	32.52	0.48	2.399	3.053	0.272614
SBR-3571	382	581349	3883984	11	286.2072	1377	29.69	0.51	10.356	11.649	0.124855
SBR-3571	393	581349	3883984	11	286.2072	1241	40.64	0.4	3.757	4.243	0.129359
SBR-3571	383	581367	3883971	11	285.9024	1399	36.21	0.56	11.009	12.719	0.155327
SBR-3571	384	581367	3883971	11	285.9024	1817	16.23	0.6	28.751	32.242	0.121422
SBR-3571	385	581367	3883971	11	285.9024	1853	16.13	0.59	34.197	38.465	0.124806
SBR-3571	386	581367	3883971	11	285.9024	1855	16.22	0.58	14.097	15.134	0.073562
SBR-3571	400	581300	3883933	11	292.608	1780	26.45	0.54	12.465	14.501	0.163337
SBR-3571	401	581366	3883996	11	292.608	1560	22.41	0.45	7.809	8.017	0.026636
SBR-3571	397	581371	3883981	11	292.608	1692	16.73	0.53	20.448	22.629	0.106661

Site Number	LB#	UTM Easting	UTM Northing	UTM Zone	Elevation (m)	Average Age (AD)	Error (in years)	Thickness (cm)	(D) Dry Sample Wt	(S) Saturated Sample Wt	H20 Absorption
SBR-3571	402	581316	3884005	11	292.608	1358	39.16	0.47	5.116	5.556	0.086005
SBR-5417	250	580141	3886500	11	259.065	1010	115.93	0.43	1.64	1.83	0.115854
SBR-5417	251	580141	3886502	11	262.539	1353	98.82	0.62	3.73	4.37	0.171582
SBR-5417	254	580145	3886504	11	261.375	1010	142.93	0.53	4.02	4.67	0.161692
SBR-5417	255	580143	3886501	11	262.249	1418	95.25	0.49	3.95	4.59	0.162025
SBR-5417	256	580143	3886502	11	259.844	1322	83.93	0.6	3.58	4.1	0.145251
SBR-5417	257	580149	3886501	11	260.257	1150	115	0.55	7.25	8.04	0.108966
SBR-5417	252	580099	3886520	11	261.289	1486	66.78	0.71	5.19	5.98	0.152216
SBR-5417	253	580104	3886519	11	262.399	1300	133.61	0.5	3.1	3.52	0.135484
SBR-5417	241	580090	3886429	11	260.564	1294	98.53	0.6	6.48	7.3	0.126543
SBR-5421	399	581366	3883972	11	292.608	1371	29.93	0.5	7.28	8.192	0.125275

Site Number	LB#	UTM Easting	UTM Northing	UTM Zone	Elevation (m)	Average Age (AD)	Error (in years)	Thickness (cm)	(D) Dry Sample Wt	(S) Saturated Sample Wt	H20 Absorption
SBR-5421	404	582046	3883843	11	286.512	1825	20.18	0.53	27.416	31.009	0.131055
SBR-5421	398	582046	3883844	11	286.512	1842	14.55	0.44	10.439	11.75	0.125587
SBR-5421	405	582046	3883844	11	286.512	1703	30.88	0.53	15.124	17.295	0.143547
SBR-5421	406	582047	3883845	11	286.512	1864	16.41	0.58	19.961	22.626	0.13351
SBR-5421	407	582049	3883844	11	286.512	1795	21.45	0.62	39.906	44.754	0.121485

APPENDIX E

ELEMENTS CONCENTRATIONS FROM ICP-MS AND XRF ANALYSES

ICP-MS Dosimetry Samples (in parts per million)

Sample Number	Na	Mg	Al	Si	K	Ca	Sc	Ti	V	Cr	Mn	Fe
LB241-1	2532.79	2317.95	31064.25	53282.74	10522.73	14410.73	9.63	1223.53	36.02	17.70	374.18	17909.50
LB241-2	3509.73	2614.37	39124.58	72442.71	12721.66	19444.61	10.72	1784.11	38.79	24.47	317.75	19236.26
LB250-1	799.11	1643.70	23755.57	29662.70	7708.87	13773.25	5.71	725.07	17.24	14.49	215.67	10611.57
LB250-2	1117.11	1630.58	26889.12	34145.64	7323.37	14790.03	5.30	564.34	15.75	20.31	152.26	10248.52
LB251-1	1338.75	1692.43	24483.15	35676.77	8997.59	8482.98	6.03	920.20	16.95	9.80	250.52	10033.87
LB251-2	1736.72	1874.19	24935.21	43787.54	8513.27	10476.41	6.32	830.01	19.23	13.31	226.75	10628.57
LB252-1	999.23	2942.88	48542.93	48778.36	13218.97	20616.17	8.64	1299.22	26.76	13.91	306.89	18269.67
LB252-2	2770.87	4571.09	106957.75	95436.34	20541.82	41331.13	13.25	1357.71	36.15	26.77	358.60	26359.11
LB253-1	1337.55	2783.66	26695.41	51006.37	8851.30	18429.93	8.41	1340.11	35.98	19.69	338.47	18442.40
LB253-2	1765.86	3072.47	30874.77	62069.12	9828.26	21798.66	8.96	1452.73	36.35	27.42	284.44	19284.42
LB254-1	2113.87	3131.55	38874.73	67477.58	12930.59	20815.13	11.90	1807.15	41.78	21.09	581.77	23561.14
LB254-2	2765.22	3733.59	45955.34	88827.19	14492.60	26067.22	13.65	1940.83	45.85	33.11	518.84	26822.64
LB255-1	606.13	983.34	11567.84	22283.71	3526.49	8536.93	2.99	423.80	10.74	10.73	106.67	6535.33
LB255-2	941.63	1549.76	27859.89	35819.20	6681.68	13018.75	4.69	595.23	12.85	12.05	150.78	9515.67
LB256-1	1507.48	1874.10	22363.25	38972.16	7827.56	10121.99	6.60	958.00	27.34	15.61	304.84	13762.20
LB256-2	1953.20	2072.45	27890.46	47756.30	9076.01	12113.86	8.00	987.60	26.71	23.64	249.83	14447.76
LB257-1	2530.18	3160.32	49781.07	67954.11	16735.52	18684.75	10.44	1572.38	34.68	13.90	577.14	22477.51
LB257-2	4360.43	4602.83	67365.03	108856.62	20902.38	28161.10	13.77	1770.28	43.54	27.10	611.73	29818.09

ICP-MS Dosimetry Continued

Sample Number	Ni	Co	Cu	Zn	As	Rb	Sr	Y	Zr	Nb	In	Sn
LB241-1	61.15	4.66	11.55	46.35	2.78	39.23	563.80	14.00	28.82	4.97	56.67	0.47
LB241-2	229.88	4.97	12.81	49.27	3.74	44.90	811.10	18.97	49.06	7.53	56.67	0.52
LB250-1	305.80	2.58	6.02	25.00	1.53	16.28	331.46	4.94	15.28	2.74	56.67	0.26
LB250-2	371.44	2.61	6.78	28.47	1.80	15.90	385.47	5.27	90.32	3.14	56.67	0.28
LB251-1	426.71	3.09	7.19	30.03	3.12	27.86	336.94	7.27	24.90	4.34	56.67	0.34
LB251-2	478.53	3.61	8.17	33.58	3.51	29.22	462.08	9.38	44.83	6.21	56.67	0.39
LB252-1	126.81	3.85	9.64	27.97	2.01	26.71	399.97	7.68	27.43	5.22	56.67	0.44
LB252-2	183.80	5.85	15.43	35.15	4.73	36.85	816.30	16.26	36.27	8.09	56.67	0.76
LB253-1	10.61	5.14	14.76	45.90	2.56	40.08	493.46	7.05	26.51	4.62	56.67	0.40
LB253-2	12.21	5.60	15.91	46.55	2.82	41.14	664.60	9.19	28.46	5.34	56.67	0.49
LB254-1	749.20	6.29	19.27	67.90	3.75	63.89	667.80	17.06	197.79	7.56	56.67	0.66
LB254-2	953.84	7.47	26.12	78.79	5.28	66.90	911.62	21.11	118.26	9.70	56.67	0.94
LB255-1	37.92	1.64	4.44	16.41	0.90	11.47	220.68	2.51	11.84	1.79	56.67	0.17
LB255-2	46.29	2.18	5.51	14.46	1.13	14.18	307.89	3.86	13.92	2.55	56.67	0.26
LB256-1	223.52	3.68	14.17	48.38	1.91	31.03	342.79	9.86	32.13	3.98	56.67	0.35
LB256-2	243.17	3.92	15.29	49.92	2.76	30.97	449.86	14.26	33.88	4.87	56.67	0.48
LB257-1	14.57	5.11	14.80	42.15	3.32	60.08	507.47	12.56	35.21	7.64	56.67	0.69
LB257-2	21.24	7.19	20.32	53.85	5.03	70.37	831.22	23.42	44.39	11.06	56.67	0.96

ICP-MS Dosimetry Continued

Sample Number	Sb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy
LB241-1	0.21	0.99	346.10	36.08	51.81	5.37	22.15	3.99	0.59	4.50	0.44	3.08
LB241-2	0.33	1.23	440.55	45.08	55.94	6.62	29.78	5.62	0.87	6.16	0.56	4.63
LB250-1	0.09	0.47	164.06	15.48	24.20	2.57	10.61	1.95	0.32	2.19	0.18	1.32
LB250-2	0.14	0.52	131.51	13.33	18.33	2.19	9.03	1.78	0.30	1.94	0.17	1.30
LB251-1	0.18	0.96	226.58	16.80	24.63	2.86	12.60	2.41	0.36	2.68	0.24	1.80
LB251-2	0.34	1.03	238.41	18.56	27.20	3.27	14.63	3.11	0.45	3.32	0.30	2.37
LB252-1	0.12	0.85	192.16	22.65	33.24	3.93	15.63	2.78	0.48	3.03	0.29	1.87
LB252-2	0.41	1.41	276.99	37.86	49.76	6.51	27.31	5.48	0.91	6.55	0.61	4.13
LB253-1	0.14	0.96	250.32	24.56	41.04	4.09	15.62	2.63	0.45	2.91	0.26	1.77
LB253-2	0.24	1.05	255.32	27.76	42.51	4.44	18.21	3.75	0.53	3.83	0.30	2.62
LB254-1	0.27	1.43	299.30	47.59	78.63	7.03	28.43	5.16	0.75	5.80	0.55	4.04
LB254-2	0.36	1.68	306.31	60.62	87.95	9.01	38.31	7.34	1.03	7.80	0.67	5.27
LB255-1	0.05	0.33	71.36	6.59	8.74	1.49	4.63	1.05	0.17	1.03	0.11	0.74
LB255-2	0.06	0.47	112.85	9.11	11.60	2.15	7.08	1.51	0.27	1.59	0.17	1.22
LB256-1	0.13	0.78	270.85	26.71	40.27	4.01	16.54	2.82	0.41	3.31	0.31	2.38
LB256-2	0.21	0.89	249.42	31.27	40.94	5.13	23.24	4.43	0.66	4.63	0.44	3.44
LB257-1	0.22	1.32	232.59	46.09	67.84	6.45	25.73	4.48	0.70	5.03	0.44	2.99
LB257-2	0.37	1.86	306.39	57.14	87.36	9.03	36.36	6.95	1.16	7.87	0.59	4.99

ICP-MS Dosimetry Continued

Sample Number	Ho	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U
LB241-1	0.52	1.77	0.22	1.69	0.22	1.12	0.37	6.10	15.99	0.82
LB241-2	0.69	2.36	0.27	3.04	0.24	1.80	0.74	7.12	19.56	0.84
LB250-1	0.21	0.70	0.08	0.82	0.08	0.58	0.23	2.33	5.47	0.43
LB250-2	0.23	0.70	0.08	0.80	0.07	2.06	0.28	2.73	5.75	0.40
LB251-1	0.29	0.91	0.12	0.97	0.12	0.83	0.35	3.12	6.47	0.54
LB251-2	0.37	1.31	0.13	1.30	0.12	1.62	0.50	3.76	7.04	0.62
LB252-1	0.34	1.02	0.14	1.17	0.14	1.02	0.44	3.59	8.78	0.66
LB252-2	0.60	1.98	0.28	2.18	0.18	1.60	0.70	7.48	14.14	0.91
LB253-1	0.29	0.95	0.11	0.94	0.11	0.91	0.39	4.79	9.37	0.65
LB253-2	0.36	1.28	0.13	1.19	0.13	1.14	0.42	5.31	11.73	0.70
LB254-1	0.67	2.11	0.25	2.28	0.27	3.60	0.60	7.87	25.43	1.01
LB254-2	0.80	2.76	0.30	2.93	0.32	3.07	0.78	9.05	30.32	1.11
LB255-1	0.13	0.40	0.05	0.41	0.05	0.51	0.15	1.45	3.51	0.24
LB255-2	0.20	0.67	0.06	0.67	0.08	0.63	0.23	2.08	5.49	0.32
LB256-1	0.40	1.23	0.15	1.28	0.14	0.90	0.34	5.30	10.99	0.60
LB256-2	0.50	1.82	0.21	1.87	0.18	1.26	0.40	6.57	12.67	0.64
LB257-1	0.48	1.53	0.21	1.68	0.22	1.31	0.54	7.36	22.25	0.98
LB257-2	0.71	2.48	0.27	2.97	0.28	2.05	0.83	10.15	32.97	1.38

ICP-MS Radiation Samples (in parts per million)

Sample Number	Na	Mg	Al	Si	K	Ca	Sc	Ti	V	Cr	Mn	Fe
LB241-1	630.10	254.12	10528.36	9977.43	3119.67	1157.43	1.87	197.26	2.23	7.13	36.54	1314.02
LB241-2	897.62	634.32	16967.14	17824.84	4567.53	2634.00	3.40	284.57	5.44	6.64	52.50	2572.11
LB250-1	1171.39	245.53	17944.74	14551.02	4088.74	2107.37	2.39	116.65	2.36	13.02	43.16	1332.62
LB250-2	3204.04	333.52	48637.42	35507.39	8401.23	3547.57	4.12	146.78	4.06	13.81	52.90	1750.84
LB251-1	1852.81	216.67	16740.53	24266.57	5254.03	1838.89	2.46	135.58	1.99	8.80	29.57	1133.81
LB251-2	4851.22	344.64	46032.40	57636.87	10157.36	4179.08	4.68	174.99	3.37	11.28	44.83	1602.97
LB252-1	1206.24	166.92	10177.90	14589.01	3528.58	1406.38	1.77	148.95	1.57	5.90	28.20	974.39
LB252-2	5742.73	405.83	52818.67	66216.97	13735.92	42868.36	5.40	1598.66	3.92	10.04	57.06	1633.49
LB253-1	1256.89	191.36	13930.96	14959.03	3732.70	1287.20	1.95	104.04	1.74	7.76	53.50	1270.77
LB253-2	1999.87	269.54	24631.73	25446.58	6819.29	1881.74	2.50	667.52	2.88	10.36	86.13	1224.08
LB254-1	944.19	139.68	11278.85	14834.60	4126.60	1013.90	1.60	83.07	1.37	6.75	41.45	890.87
LB254-2	1927.44	205.95	20678.31	25478.28	4237.86	2051.75	2.21	131.58	2.61	8.10	52.57	3370.62
LB255-1	816.46	216.79	7315.22	11453.92	2554.58	1238.85	1.63	219.88	2.06	6.55	33.25	1387.13
LB255-2	2099.75	347.33	21872.93	28095.83	4432.20	3605.70	3.76	1517.19	4.91	8.72	141.01	3795.85
LB256-1	1159.39	171.80	25257.27	23646.86	7147.49	1454.88	2.95	92.07	2.03	9.19	31.52	1267.45
LB256-2	5522.10	267.99	96031.03	118048.44	33357.31	4971.31	7.06	157.06	5.58	15.37	62.43	2318.37
LB257-1	1171.20	167.12	10393.09	17938.38	3705.22	1206.95	1.98	208.56	1.88	6.56	51.25	1127.74
LB257-2	2576.23	266.84	22459.43	38210.13	5743.29	3266.02	3.54	617.39	3.26	9.15	82.54	1676.57

ICP-MS Radiation Continued

Sample Number	Ni	Co	Cu	Zn	As	Rb	Sr	Y	Zr	Nb	In	Sn
LB241-1	0.70	0.31	0.75	6.28	0.37	9.05	27.51	7.04	9.12	1.67	56.67	0.14
LB241-2	1.66	0.65	0.93	6.21	0.56	10.98	83.32	7.06	7.79	1.94	56.67	0.16
LB250-1	1.28	0.34	1.29	7.09	0.61	10.96	75.02	3.83	13.71	1.20	56.67	0.11
LB250-2	1.53	0.63	1.38	8.51	0.73	18.07	136.72	6.67	17.79	1.51	56.67	0.15
LB251-1	0.60	0.31	0.93	6.49	0.68	19.43	86.04	4.42	7.70	1.45	56.67	0.10
LB251-2	1.32	0.58	1.67	8.00	0.69	35.74	200.77	7.88	13.47	2.04	56.67	0.18
LB252-1	0.46	0.24	0.71	5.72	0.30	13.38	65.18	3.24	7.95	1.51	56.67	0.10
LB252-2	1.26	0.63	1.82	8.41	0.90	46.02	298.32	9.05	22.32	3.44	56.67	0.26
LB253-1	0.50	0.32	0.77	6.06	0.28	11.51	61.59	3.77	6.11	0.89	56.67	0.12
LB253-2	1.07	0.55	1.74	6.24	0.42	24.37	77.15	5.27	7.86	3.42	56.67	0.19
LB254-1	0.43	0.27	0.69	4.62	0.27	20.42	60.65	3.44	5.78	0.96	56.67	0.06
LB254-2	1.04	0.53	0.98	6.60	0.41	12.80	98.76	5.29	7.57	1.77	56.67	0.11
LB255-1	0.52	0.30	0.68	5.10	0.36	9.86	45.41	3.39	9.16	1.38	56.67	0.21
LB255-2	1.31	0.60	1.12	7.50	0.74	12.34	98.77	13.45	15.62	8.66	56.67	0.44
LB256-1	0.60	0.28	2.26	6.29	1.32	19.91	69.54	5.73	46.49	1.35	56.67	0.07
LB256-2	2.41	0.65	3.94	18.76	2.72	101.73	241.39	7.70	19.14	2.78	56.67	0.27
LB257-1	0.49	0.27	0.92	5.48	0.75	14.71	52.36	4.03	7.50	1.33	56.67	0.09
LB257-2	1.37	0.48	1.35	7.64	0.52	19.52	135.51	18.02	11.98	4.24	56.67	0.17

ICP-MS Radiation Continued

Sample Number	Sb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy
LB241-1	0.06	0.11	49.62	11.41	10.45	1.43	5.72	1.43	0.14	1.64	0.17	1.53
LB241-2	0.12	0.20	95.67	7.68	7.76	1.46	6.39	1.82	0.22	1.97	0.21	1.85
LB250-1	0.11	0.15	49.49	5.75	5.56	1.10	4.54	1.11	0.14	1.15	0.09	0.98
LB250-2	0.09	0.29	127.19	9.12	9.86	2.14	10.50	3.01	0.41	3.00	0.23	2.09
LB251-1	0.05	0.15	90.75	8.30	6.61	1.60	6.67	1.54	0.18	1.67	0.12	1.16
LB251-2	0.08	0.27	147.02	9.45	8.78	2.06	9.07	2.44	0.37	2.67	0.24	2.18
LB252-1	0.03	0.11	73.05	4.73	4.65	0.83	3.57	0.85	0.11	0.96	0.10	0.81
LB252-2	0.15	0.29	227.12	10.81	11.79	2.47	10.93	2.62	0.42	2.96	0.31	2.70
LB253-1	0.03	0.13	76.57	4.67	4.81	0.93	4.14	1.08	0.13	1.18	0.12	0.97
LB253-2	0.06	0.18	162.18	5.33	5.59	1.18	5.45	1.58	0.21	1.60	0.16	1.41
LB254-1	0.02	0.11	126.71	4.78	5.19	0.82	3.52	0.81	0.10	0.89	0.09	0.77
LB254-2	0.05	0.14	69.62	4.69	5.14	0.96	4.40	1.25	0.15	1.59	0.16	1.43
LB255-1	0.05	0.10	58.31	5.12	5.64	0.98	4.14	0.96	0.18	1.03	0.10	0.83
LB255-2	0.06	0.18	100.04	19.15	35.26	6.02	29.44	6.31	0.84	5.41	0.46	3.73
LB256-1	0.06	0.12	111.31	7.72	7.10	1.41	6.08	1.46	0.15	1.49	0.14	1.34
LB256-2	0.16	0.49	624.47	12.47	10.97	2.42	11.19	2.37	0.29	2.84	0.25	2.20
LB257-1	0.05	0.11	77.20	9.87	9.87	1.69	7.29	1.48	0.17	1.43	0.12	1.01
LB257-2	0.06	0.17	109.05	9.38	9.48	2.04	9.74	3.02	0.42	3.57	0.46	4.35

ICP-MS Radiation Continued

Sample Number	Ho	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U
LB241-1	0.23	0.89	0.10	1.00	0.09	0.31	0.12	1.10	6.98	0.12
LB241-2	0.27	1.06	0.11	1.07	0.10	0.35	0.14	1.58	3.24	0.14
LB250-1	0.13	0.53	0.06	0.51	0.05	0.43	0.10	2.47	5.14	0.12
LB250-2	0.28	0.90	0.07	0.97	0.07	0.68	0.14	2.78	4.46	0.17
LB251-1	0.16	0.60	0.06	0.56	0.06	0.30	0.10	7.98	14.64	0.18
LB251-2	0.28	1.10	0.14	1.12	0.11	0.65	0.17	3.87	14.17	0.21
LB252-1	0.12	0.42	0.05	0.45	0.04	0.27	0.11	1.46	1.74	0.08
LB252-2	0.41	1.41	0.18	1.76	0.13	1.03	0.22	4.49	4.62	0.37
LB253-1	0.14	0.49	0.05	0.42	0.05	0.20	0.08	1.83	2.43	0.07
LB253-2	0.20	0.80	0.08	0.79	0.08	0.34	0.30	2.70	3.82	0.16
LB254-1	0.12	0.43	0.05	0.44	0.04	0.21	0.09	1.88	14.81	0.21
LB254-2	0.20	0.78	0.08	0.83	0.09	0.29	0.14	2.08	23.14	0.31
LB255-1	0.12	0.42	0.05	0.42	0.05	0.32	0.12	1.45	3.61	0.09
LB255-2	0.51	1.79	0.19	1.86	0.18	0.92	0.70	2.02	4.39	0.15
LB256-1	0.20	0.77	0.09	0.79	0.10	1.07	0.12	2.21	12.40	0.13
LB256-2	0.28	1.31	0.13	1.16	0.11	0.81	0.26	9.08	5.36	0.20
LB257-1	0.13	0.49	0.06	0.47	0.05	0.29	0.11	1.94	7.88	0.12
LB257-2	0.63	2.40	0.28	2.12	0.21	0.51	0.75	2.77	4.94	0.18

XRF Dosimetry Samples (in parts per million)

Sample Number	Mg	Si	K	Ca	Sc	Ti	V	Cr
LB_378	5,980.31	141,078.25	17,368.64	5,574.63	14.34083	3,755.59	143.0772	35.34165
LB_379	7,109.88	142,587.46	20,163.03	25,182.00	13.0591	3,632.07	145.3089	38.79652
LB_380	10,162.93	150,778.37	23,002.41	31,035.35	11.87553	2,366.19	122.8038	52.62263
LB_381	6,119.19	141,954.05	19,435.34	8,738.70	14.04792	3,699.58	145.8713	36.23683
LB_382	8,161.90	145,792.48	20,959.82	13,906.55	13.80676	3,249.04	158.3432	42.04605
LB_383	6,637.37	141,269.74	18,964.01	15,243.15	13.61424	3,515.06	144.6598	38.43961
LB_384	7,325.16	145,933.86	21,095.75	16,937.65	13.33039	3,439.01	139.8949	39.11171
LB_385	7,228.61	145,416.57	21,142.96	16,631.27	13.38933	3,483.58	142.5175	38.80337
LB_386	6,514.20	140,275.15	18,927.37	10,695.68	13.71274	3,603.18	143.7043	36.19993
LB_387	13,535.45	150,227.04	26,070.46	21,191.42	11.45582	-385.808	42.96357	65.82053
LB_388	6,267.40	138,759.49	17,588.91	9,899.02	13.66785	3,557.80	141.7991	35.03034
LB_389	9,075.98	149,590.26	22,785.59	18,931.65	13.31381	2,837.58	143.7074	48.81885
LB_390	8,044.63	143,590.42	20,801.47	15,040.11	13.41204	3,459.46	143.358	42.52782
LB_391	7,527.46	145,136.76	20,577.18	16,024.07	12.98433	2,815.98	129.7773	42.30595
LB_392	6,147.01	140,247.37	18,047.91	4,149.97	14.25967	3,730.38	141.0718	33.94587
LB_393	6,413.43	138,887.76	16,889.39	8,885.17	13.7356	3,535.36	141.9041	36.81395
LB_394	6,546.91	141,257.56	21,934.38	5,630.76	14.15793	3,601.19	146.9937	34.51641
LB_395	6,403.85	142,157.26	22,758.50	5,614.72	14.23191	3,733.69	144.5073	34.11037
LB_397	7,697.60	140,586.07	21,163.90	11,787.88	13.59097	3,378.96	153.9097	40.38208
LB_398	8,068.92	139,611.33	20,727.23	14,269.06	12.88045	3,019.86	136.7128	42.15425
LB_399	7,238.11	142,421.01	19,957.38	14,686.59	13.62152	3,301.30	153.2935	44.27491
LB_400	8,951.10	154,564.46	23,127.30	18,102.78	13.88152	2,933.70	148.9137	49.06473
LB_401	9,211.96	147,275.31	20,878.73	29,864.89	12.9785	2,998.49	149.4349	47.9521
LB_402	7,840.68	140,579.35	19,855.81	15,486.67	13.26401	2,878.98	152.5872	43.31003
LB_403	4,453.63	134,707.83	12,617.42	-2,405.23	14.8429	3,301.60	113.5939	30.43057
LB_404	7,658.65	144,367.27	20,522.61	13,402.33	13.44615	3,548.50	141.7649	37.63937
LB_405	7,769.53	143,307.90	19,664.48	10,087.50	13.98519	3,364.72	149.7665	45.41184
LB_406	7,648.05	146,251.95	21,526.09	14,966.51	13.45732	3,293.93	147.2687	42.42312
LB_407	8,012.69	149,316.52	22,400.48	17,447.39	13.33428	3,261.79	144.9974	42.7816
LB_408	7,155.87	146,615.59	20,783.76	10,707.72	13.91591	3,317.73	150.7905	42.05101
LB_409	7,243.91	149,383.26	19,978.19	7,830.97	14.24406	3,378.05	138.6642	40.6362

XRF Dosimetry Continued

Sample Number	Mn	Fe	Co	Ni	Cu	Zn	As	Pb
LB_378	159.3306	13,478.76	4.54781	13.46977	95.62593	34.06079	1.15443	44.66089
LB_379	185.751	10,292.77	3.010925	14.12721	89.0291	33.53553	0.968947	46.01788
LB_380	136.2772	9,851.97	3.210665	86.75563	81.492	28.74034	1.978671	26.02863
LB_381	109.7977	10,962.73	3.669589	10.24899	67.84815	32.42835	1.896717	45.58523
LB_382	111.0251	11,569.63	4.057569	83.20435	68.99548	33.36564	1.765565	26.59878
LB_383	135.1067	12,391.95	3.881163	17.20827	145.2314	67.80533	10.03423	39.00015
LB_384	139.216	10,080.56	3.163273	11.72652	64.8607	32.07086	2.39838	43.2572
LB_385	169.9057	10,443.59	3.226048	12.60495	61.68718	32.80142	0.865422	47.1299
LB_386	160.3183	10,236.70	3.25762	10.11924	63.65115	34.82483	2.665313	42.38268
LB_387	120.3135	9,447.93	3.148111	36.11291	66.3475	27.75631	0.210964	44.95971
LB_388	116.4483	9,396.64	3.078333	13.5166	65.02702	33.49076	0.83664	47.32181
LB_389	121.4161	10,615.79	3.661918	56.30633	70.01593	28.83642	-0.51741	42.73299
LB_390	102.0786	10,646.79	3.54423	21.20894	66.83177	28.33996	-1.38591	54.07072
LB_391	125.9403	10,656.00	3.49649	34.76798	86.64188	33.0037	3.006941	34.69413
LB_392	65.93799	11,069.10	4.00048	87.26788	49.38924	37.87285	3.510804	18.7073
LB_393	119.6195	9,366.36	3.041459	29.31203	53.73204	28.69794	-1.84714	55.15586
LB_394	87.29087	10,539.25	3.665999	13.58832	43.18671	27.72229	1.742355	46.62814
LB_395	106.1109	10,871.73	3.831904	11.13855	46.28492	27.10779	1.692502	46.88052
LB_397	123.9481	9,675.06	3.249674	45.37112	53.39332	30.43991	-1.30217	48.79088
LB_398	93.16342	9,516.14	3.206763	55.0183	62.28722	35.80115	2.983393	29.0127
LB_399	161.33	11,087.37	3.543152	81.68277	70.75223	29.72373	-0.71934	38.15085
LB_400	149.5036	11,533.30	3.548376	47.09488	84.67925	38.64972	3.954762	27.14577
LB_401	168.3164	11,235.43	3.68856	51.33228	71.64807	30.34843	-0.86881	45.44391
LB_402	117.0118	10,275.57	3.592984	48.906	62.43397	32.61507	-0.20831	41.87937
LB_403	119.9095	11,953.05	4.325608	127.1309	78.54233	33.46499	1.614029	17.66873
LB_404	84.14296	9,506.83	3.305554	80.77669	60.10891	26.75225	0.638442	33.44999
LB_405	177.2873	12,741.83	4.179347	149.5907	86.5887	29.53558	0.173588	21.60593
LB_406	141.181	10,686.61	3.648335	239.3851	75.32292	32.59544	-0.5154	10.02973
LB_407	135.7569	10,846.63	3.688354	89.1017	79.65727	55.5544	0.342556	24.74937
LB_408	160.6527	10,888.72	3.497891	49.39745	44.09196	42.51706	-0.47335	40.76095
LB_409	116.9571	14,086.23	5.152071	29.09799	65.03315	28.87831	2.633433	38.73523

XRF Dosimetry Continued

Sample Number	Th	Rb	U	Sr	Zr
LB_378	5.288499	36.92976	2.019585	186.3878	75.50239
LB_379	4.431536	45.17022	1.488441	198.5355	65.52647
LB_380	5.378414	40.31532	1.716002	163.0625	72.78885
LB_381	4.857761	32.33961	2.059479	138.2357	65.0491
LB_382	4.074623	35.73482	2.030641	128.417	73.52472
LB_383	6.979681	65.04819	1.002698	342.7522	72.9268
LB_384	4.689593	39.51236	1.725409	127.5427	64.85982
LB_385	4.827467	43.99429	1.635273	117.3573	65.72409
LB_386	4.897109	48.17026	1.495939	125.8805	66.17411
LB_387	4.450155	37.43312	1.857461	135.3513	69.08994
LB_388	5.42324	42.56149	1.7212	134.6197	64.75897
LB_389	3.701222	30.2635	2.070585	149.4042	73.00077
LB_390	2.173048	30.4174	2.138745	151.2175	68.20977
LB_391	4.454487	35.85171	1.918128	196.3473	72.62236
LB_392	4.362209	39.70021	2.049943	74.03331	78.44574
LB_393	2.95458	26.17029	2.115327	108.2926	62.439
LB_394	7.67671	105.9371	0.58968	50.23189	61.70207
LB_395	7.672838	115.2635	0.344463	52.76605	64.04659
LB_397	3.508307	28.71054	2.097189	95.92863	66.59698
LB_398	3.770922	36.21464	1.895174	124.3807	70.58247
LB_399	4.38264	32.6059	1.999923	125.8386	70.94879
LB_400	4.294417	45.20342	1.694858	177.3793	70.71776
LB_401	4.31305	35.70959	1.893278	149.4004	66.52157
LB_402	4.348591	35.6935	1.956342	124.3048	69.66007
LB_403	4.430295	39.30351	2.008872	130.3477	84.98665
LB_404	3.276993	39.67644	1.954971	103.5838	72.52475
LB_405	4.28212	36.06216	1.998077	146.6512	76.34207
LB_406	4.063018	39.68591	1.851545	124.3541	90.34649
LB_407	4.786236	47.26729	1.672506	158.3852	80.07852
LB_408	6.296708	52.35994	1.550656	62.68219	64.62044
LB_409	4.491559	30.74652	2.24343	142.735	79.98281

XRF Radiation Samples (in parts per million)

Sample Number	Mg	Si	K	Ca	Sc	Ti	V	Cr
LB_378	7,882.60	138,007.86	19,250.87	7,508.62	12.66221	2,221.11	81.91477	42.19442
LB_379	6,114.93	136,730.38	16,163.82	3,156.69	13.75445	3,341.06	133.8729	33.13904
LB_381	7,159.58	137,196.77	18,173.70	7,214.41	13.00227	2,868.16	120.3715	36.45723
LB_382	6,948.98	137,957.33	18,098.77	7,257.61	12.67301	2,567.98	93.24049	35.45802
LB_383	6,564.09	132,702.43	18,769.10	6,802.29	13.51163	3,396.57	160.7534	37.14187
LB_384	6,010.50	138,550.56	16,706.08	9,087.04	13.82686	3,578.64	141.0692	35.48857
LB_387	6,705.08	140,855.90	17,653.01	8,937.31	13.97125	3,574.58	137.1981	39.84235
LB_389	6,948.98	137,957.33	18,098.77	7,257.61	12.67301	2,567.98	93.24049	35.45802
LB_393	6,762.28	137,402.11	16,053.23	4,513.21	13.29239	2,770.73	112.1485	35.56375
LB_394	7,811.09	134,229.17	19,717.69	10,796.26	11.51195	1,135.48	88.04184	41.35484
LB_397	9,605.31	136,193.95	19,400.76	8,413.31	9.937337	-1,747.15	-77.10363	43.64895
LB_398	5,950.47	137,364.20	16,452.33	5,536.48	13.91734	3,509.53	139.8687	34.43001
LB_399	7,238.11	142,421.01	19,957.38	14,686.59	13.62152	3,301.30	153.2935	44.27491
LB_400	10,118.84	139,800.62	22,537.15	13,023.57	9.968485	-1,032.39	-13.06005	40.29156
LB_401	12,269.09	120,411.02	23,228.13	4,817.92	3.253714	-15,810.75	-535.746	60.22523
LB_402	14,192.24	134,569.32	26,789.27	18,573.78	7.211742	-2,807.72	-132.786	59.05918
LB_403	12,612.97	138,102.78	24,167.97	15,038.54	9.765247	-2,214.89	-24.95435	52.91198
LB_404	9,279.11	146,690.85	22,601.51	16,202.46	12.57732	2,328.56	113.1753	43.90994
LB_406	9,404.72	151,869.71	22,133.71	20,383.46	13.03632	3,247.43	118.1241	47.15661
LB_407	7,357.56	141,214.09	19,101.29	12,724.95	13.50246	3,585.95	141.3016	37.99547
LB_408	9,212.92	139,027.09	23,763.95	11,450.67	12.14831	2,402.63	92.52637	39.34751
LB_409	8,037.39	138,284.67	19,621.45	9,392.04	11.44685	596.2553218	41.31568	39.89649

XRF Radiation Continued

Sample Number	Mn	Fe	Co	Ni	Cu	Zn	As	Pb
LB_378	85.37885	8,686.46	2.982716	3.898219	65.66928	20.6512	-2.360998	63.96102
LB_379	51.14777	6,900.95	2.397142	0.766621	52.11721	20.1909	-2.842411	67.33031
LB_381	60.92676	8,005.05	2.759813	7.340531	69.80946	23.84389	-0.355221	55.30527
LB_382	37.83476	7,154.05	2.534159	1.756608	59.50984	21.93965	-1.981052	63.14006
LB_383	87.95644	8,022.06	2.776803	7.734546	69.54707	21.78373	-1.231716	58.81067
LB_384	104.9622	9,593.11	3.209331	6.784492	73.84538	27.74651	-0.896477	56.52795
LB_387	172.1792	12,447.43	4.093647	8.961066	80.33566	30.1921	-0.59775	53.48735
LB_389	109.7484	7,902.56	2.600699	4.970753	71.34673	23.63445	1.919254	48.92756
LB_393	71.58665	8,016.52	2.786596	4.447435	60.93668	21.04634	-2.393549	64.04174
LB_394	108.96	7,630.14	2.554168	2.628912	75.61166	23.56235	-2.270783	62.76909
LB_397	100.3104	7,174.60	2.418108	2.871031	64.06308	22.68266	-2.359644	64.48053
LB_398	119.0547	8,884.62	2.938907	2.59121	63.59256	23.5302	-2.980205	66.76387
LB_399	91.56366	7,207.15	2.391635	1.544822	61.52226	22.53205	-1.41107	60.47531
LB_400	84.04643	7,894.46	2.623899	6.643797	77.6984	24.70313	0.092118	53.21976
LB_401	84.04643	7,894.46	2.623899	6.643797	77.6984	24.70313	0.092118	53.21976
LB_402	60.9311	7,132.15	2.439963	0.311034	63.80509	22.90071	-1.921359	63.21111
LB_403	89.60956	8,687.15	2.892213	5.801263	81.37457	26.76083	1.586862	49.22653
LB_404	77.11094	8,317.95	2.933337	3.06088	65.60089	23.68517	-1.3613	60.21599
LB_406	117.2644	8,878.99	2.911286	3.376587	66.22903	27.27048	-1.749675	60.00226
LB_407	145.7258	10,673.32	3.471612	6.27453	69.96619	29.73958	-0.794197	54.97991
LB_408	95.64009	9,513.66	2.983871	2.875034	69.22517	25.66353	-0.372601	55.95298
LB_409	83.04004	8,610.00	2.852552	2.676575	65.49202	22.90007	-2.096633	63.1131

XRF Radiation Continued

Sample Number	Th	Rb	U	Sr	Zr
LB_378	3.875219	34.07105	2.02001	148.6263	67.50187
LB_379	2.106177	30.07181	2.080078	103.2622	63.17922
LB_381	4.18845	34.5652	1.982194	164.1988	68.75143
LB_382	3.063626	27.92907	2.158879	141.9938	64.03001
LB_383	3.359789	39.05868	1.864736	146.4152	69.34646
LB_384	3.966429	35.08891	1.94702	176.4227	65.88312
LB_387	4.618228	42.19251	1.830824	183.8513	68.36623
LB_389	3.551244	39.29174	1.729048	170.5956	69.69046
LB_393	3.347236	34.64508	2.062861	118.0391	67.62856
LB_394	4.313966	47.70208	1.560608	156.4512	62.26282
LB_397	2.980384	29.76402	1.990673	152.4261	66.53384
LB_398	2.862615	31.06761	2.047077	145.2329	63.78175
LB_399	2.882943	32.38891	1.912896	141.4929	62.64776
LB_400	4.252328	40.27357	1.782741	178.8099	62.8338
LB_401	4.252328	40.27357	1.782741	178.8099	62.8338
LB_402	2.498459	35.35804	1.943091	145.9334	62.41075
LB_403	3.61657	51.41317	1.582777	194.9547	75.75124
LB_404	3.373844	31.10116	2.068402	160.7321	65.48446
LB_406	3.208665	31.44885	2.008756	157.4273	65.06245
LB_407	3.372321	35.37365	1.926901	175.1914	66.49693
LB_408	3.221998	31.56716	2.024895	173.2645	63.17151
LB_409	2.98285	29.66339	2.096428	154.4207	66.61185

REFERENCES CITED

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Aitken, M. J.
1985 *Thermoluminescence dating.* Academic Press, London.

Aitken, M. J.
1994 Optical dating: a non-specialist review. *Quaternary science reviews.* 13(5): 503-585.

Aitken, M. J.
1998 *An introduction to optical dating : the dating of Quaternary sediments by the use of photon-stimulated luminescence.* Oxford University Press, Oxford; New York.

Bamforth, Douglas B.
1991 Technological Organization and Hunter-Gatherer Land Use: A California Example. *American Antiquity* 56(2):216-234.

Banerjee, D., A. S. Murray, L. Botter-Jensen, and A. Lang
2001 Equivalent dose estimation using a single aliquot of polymineral fine grains. *Radiation Measurements* 33(1):73-94.

Blomster, Jeffrey P., Hector Neff, and Michael D. Glascock
2005 Olmec Pottery Production and Export in Ancient Mexico Determined Through Elemental Analysis. *Science* 307(5712):1068.

Campbell, Elizabeth W. C.
1937 *The archeology of pleistocene Lake Mohave;a symposium.* Southwest Museum, Los Angeles.

Campbell,Elizabeth W.C. and William H. Campbell
1937 *The Lake Mojave Site.* Southwest Museum, Los Angeles.

Clarke, M. L., C. A. Richardson, and H. M. Rendell
1995 Luminescence dating of mojave desert sands. *Quaternary Science Reviews,* 14(7-8):783-789.

Colton, Harold S.
1958 *Pottery types of the Southwest :wares 14, 15, 16, 17; 18 : revised descriptions, Alameda Brown Ware, (H. S. Colton) Tizon Brown Ware, (Robert Euler & Henry Dobyns) Lower Colorado Buff Ware, (A. H. Schroeder) Prescott Gray Ware, (H. S. Colton) San Francisco Mt. Gray Ware, (H.S. Colton).* Vol. 3D, Northern Arizona Society of Science and Art, Flagstaff, Arizona.

Colton, Harold S.
1955 *Pottery types of the Southwest.* Northern Arizona Society of Science and Art, Flagstaff, Ariz.

Colton, Harold S.
1945 *The Patayan problem in the Colorado River Valley.* University of New Mexico Press, Albuquerque.

Dean, J. S.
1978 Independent dating in archaeological analysis. In *Advances in Archaeological Method and Theory,* Vol. 1, edited by Michael B. Schiffer, pp. 223-255. Academic Press, New York; London.

Duller, Geoff
2007 *Analyst Manual.* Vol. 3.24, Luminescence Laboratory Institute of Geography and Earth Sciences University of Wales, Aberystwyth, United Kingdom.

Duller, Geoff
1995 Luminescence dating using single aliquots: methods and applications. *Radiation Measurements* 24(3):217.

Eerkens, J. W.
2003 Residential Mobility and Pottery Use in the Western Great Basin. *Current anthropology* 44:728-737.

Eerkens, Jelmer, Hector Neff, and Michael Glascock
2002 Ceramic Production among Small-Scale and Mobile Hunters and Gatherers: A Case Study from the Southwestern Great Basin. *Journal of Anthropological Archaeology* 21(2):200-229.

Feathers, J. K.
2003 Use of luminescence dating in archaeology. *Measurement science & technology.* 14:1493-1509.

Feathers, J. K.
2006 Explaining Shell-Tempered Pottery in Prehistoric Eastern North America. *Journal of Archaeological Method and Theory* 13(2):89-133.

Gee, Henry,
1999 *In Search ofDdeep Time :Beyond the Fossil Record to a New History of Life.* Free Press, New York.

Glowacki, Donna M., Hector Neff, and California State University, Long Beach
2002 *Ceramic Production and Circulation in the Greater Southwest :Source Determination by INAA and Complementary Mineralogical Investigations.* Vol. 44, Cotsen Institute of Archaeology at UCLA, Los Angeles.

Griset, Suzanne, and Robert L. Bettinger
1986 Pottery of the Great Basin and Adjacent Areas. *Anthropological Papers*, Vol. 111. University of Utah Press, Salt Lake City, Utah.

Harvey, Adrian M., Peter E. Wigand, and Stephen G. Wells
1999 Response of alluvial fan systems to the late Pleistocene to Holocene climatic transition: contrasts between the margins of pluvial Lakes Lahontan and Mojave, Nevada and California, USA. *Catena,* 36(4):255-281.

Henderson, Julian
2000 *The science and archaeology of materials : an investigation of inorganic materials.* Routledge, London.

Hildebrand, J. A., Gross, G. T., Schaefer, J., and Neff, H.
2002 Patayan ceramic variability: Using trace elements and petrographic analysis to study brown and buff wares in southern California. In Glowacki, D. M., and Neff, H. (eds.), *Ceramic Production and Circulation in the Greater Southwest*, Cotsen Institute of Archaeology Monograph 44, University of California, Los Angeles,pp. 121–139.

Jones, Terry L., Kathryn Klar, and Society for California Archaeology
2007 *California prehistory :colonization, culture, and complexity.* AltaMira Press, Lanham, MD.

Lyman, R. L., Michael J. O'Brien, and Robert C. Dunnell
1997 *The Rise and Fall of Culture History.* Plenum, New York; London.

Lyneis, Margaret M.
1988 Tizon Brown Ware and the Problems Raised by Paddle-and-Anvil Pottery in the Mojave Desert. *Journal of California and Great Basin Anthropology* 10(2): 146-155.

Munro, Pamela, Nelie Brown, and Judith G. Crawford
1992 *A Mojave Dictionary.* Vol. 10, Department of Lingusitics, UCLA, Los Angeles, CA.

Murray AS, Wintle AG, and Wallinga J
2002 Dose estimation using quartz OSL in the non-linear region of the growth curve. *Radiation Protection Dosimetry* 101:1-4.

Murray, A. S., and A. G. Wintle
1998 Factors controlling the shape of the OSL decay curve in quartz. *Radiation Measurements.* 29(1):65-78.

Murray, A. S., and A. G. Wintle
2000 Luminescence dating of quartz using an improved single-aliquot regenerative-dose protocol. *Radiation measurements.* 32(1):57-72.

Neff, Hector
1996 Ceramics and Evolution. In *Evolutionary archaeology theory and application,* edited by Michael J. O'Brien, pp. 244 - 269. University of Utah Press, Salt Lake City.

Neff, Hector
1992 Ceramics and Evolution. *Archaeological Method and Theory* 4:141-193.

Phillips, P., J.A. Ford and J.B. Griffin
1951 *Archaeological Survey in the Lower Mississippi Alluvial Valley, 1940-1947*. Papers of the Peabody Museum of American Archaeology and Ethnology 25, pp. 61-68. Harvard University Press, Cambridge.

Pollard, A. M.
2007 *Analytical chemistry in archaeology.* Cambridge University Press, Cambridge.

Rogers, Malcolm J.
1929 *Report of an archaeological reconnaissance in the Mohave Sink region.* Vol. 1, San Diego, Calif.

Rogers, Malcolm J.
1936 Yuman Pottery Making. *San Diego Museum Papers* (2).

Rogers, Malcolm J.
1939 *Early lithic industries of the lower basin of the Colorado River and adjacent desert areas.* San Diego Museum, San Diego.

Schroeder, A. H.
1958 Lower Colorado Buff Ware: A descriptive revision. In *Pottery types of the Southwest: wares 14, 15, 16, 17, 18: revised descriptions, Alameda brown ware, (H.S. Colton), Tizon brown ware, (Robert Euler & Henry Dobyns), Lower Colorado buff ware, (A.H. Schroeder), Prescott gray ware, (H.S. Colton), San Francisco Mt. gray ware, (H.S. Colton),* edited by Harold S. Colton, Flagstaff, Ariz.

Speakman, R. J., and H. Neff
2002 Evaluation of Painted Pottery from the Mesa Verde Region using Laser Ablation-Inductively Coupled Plasma Mass-Spectrometry (LA-ICP-MS). *American Antiquity* 67:137-144.

Sutton, M. Q., M. E. Basgall, J. K. Gardner, and M. W. Allen
2007 Advances in Understanding Mojave Desert Prehistory. In *California Prehistory: Colonization, Culture, and Complexity,* edited by Terry L. Jones, Kathryn Klar and Society for California Archaeology, pp. 229-245. AltaMira Press, Lanham, MD.

Walker, M. J. C.
2005 *Quaternary Dating Methods.* J. Wiley, Chichester, England; Hoboken, NJ.

Warren, C. N.
1984 The Desert Region. In *California Archaeology,* edited by Michael J. Moratto, pp. 339-430. Academic Press, Orlando.

Wells, S. G., W. J. Brown, Y. Enzel, R. Y. Anderson, and L. D. McFadden
2003 Late Quaternary Geology and Paleohydrology of Pluvial Lake Mojave, Southern California. *Special Papers* (368):79-114.